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SOIL CLASSIFICATION DECISION SUPPORT SYSTEM USING AN EXPERT SYSTEM APPROACH

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ABSTRACT

Soil classification systems are necessary for the identification of soil properties. Expert systems can be a very powerful tool in identifying soils quickly and accurately. In this paper, an interactive and user-friendly expert decision support system was developed using an expert system shell. The system classifies soils according to the Unified Soil Classification System and the American Association of State Highway and Transportation Officials (AASHTO) system. In addition, the system classifies the swelling potential of expansive soils according to the schemes developed by Seed et al. (1962), Van der Merwe (1975), and Dakshanamurthy and Raman (1973). Randomly selected problems solved by the system showed that it is quick, accurate, simple, and easy to follow.

INTRODUCTION

A soil classification system is a language by which geotechnical engineers can communicate with each other. In this classification, soils which exhibit similar behavior are grouped together. Knowing the particular designation of a given soil makes it possible for the engineer to have a good qualitative view of the soil's behavior. The USCS and AASHTO soil classification systems are the most commonly used in civil engineering practice. The Federal Aviation Administration (FAA) of the U.S. Department of Transportation had their own soil classification system for designing airport pavement. Currently, however, the FAA uses the USCS.

Even though these popular classification systems have flow charts or tables that can be used manually, the time spent by the lab technician on the manual approach is limited since he/she needs to conduct numerous other tests. Hence, a quick and reliable computerized technique for soil classification is needed to make better utilization of the technician's time. Recantly Expert Systems are used to provide the needed solution.

Expert systems, also known as knowledge-based systems, have emerged recently as one of the more mature branches of artificial intelligence. Several authors, Sell (1985), Mohan (1990) and Turban (1992) have provided interesting reviews of expert systems development for industry, and have offered useful guidelines for expert system selection and development.

Expert systems have been used in a diverse range of civil engineering applications. In geotechnical engineering, they have been developed for applications such as retaining walls and site characterization. Furthermore, Bakeer and Morse (1988), and Sener (1991) have developed expert systems for the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system, respectively. In this paper, an interactive, user-friendly expert system was developed for both the USCS and AASHTO systems. In addition, the system can classify the swelling potential of expansive soils qualitatively according to the systems developed by Seed et al. (1962), Van der Merwe (1975), and Dakshanamurthy and Raman (1973). To the authors' knowledge, the swelling potential of expansive soils has not been addressed by the previous expert classification systems. Hence, it is a unique feature of this system.

SOIL CLASSIFICATION SYSTEM

Several soil classification systems have been mentioned in the literature, the following are brief descriptions of these systems:

Unified Soil Classification System (USCS)

The USCS was originally developed by Casagrande (1948) for the use in airfield construction and it is utilized by the U.S. Army Corps of Engineers. It was later modified by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers for applications relating to dams, foundations, and other geotechnical problems (Holtz and Kovacs 1981). At present, the USCS is used by most consulting firms and soil testing laboratories. It is generally based on the Atterberg limits for fine-grained soils and the grain size distribution for coarse-grained soils. The USCS uses the plasticity chart developed by Casagrande (1948) for fine-grained soils, which is simply the plasticity index plotted against liquid limit. A borderline, called A-line, on the plasticity chart separates clays and silts. Clayey soils plot above the A-line while silty soils plot below it.

This system classifies soils into three categories: coarse-grained, fine-grained, and highly organic soils. These categories are further divided into 15 basic soil groups (Liu and Evett 1992). Highly organic soils such as peat can be identified by their fibrous texture, dark brown or black color, and odor. They are highly compressible and have low strength, and thus they are unsuitable as construction material

The boundary between the coarse-grained (gravel and sand) and fine-grained (silt and clay) soils is No. 200 sieve (0.075 mm). Coarse-grained soils are those having less than 50% passing the No. 200 sieve. Coefficients of uniformity Cu and curvature Cc are used to characterize the particle size distribution curve. In coarse-grained soil, if more than 50% is retained on the No. 4 sieve (4.75 mm), then it is *gravel*; otherwise it is *sand*.

In coarse-grained soil, it is often required to state whether the soil is well graded (W) or poorly graded (P) depending on the grain size distribution. A soil with little fines (less than 5% passing the No. 200 sieve) in which the particle sizes are distributed over a wide range and the gradation curve is smooth and concave upward is classified as either GW or SW, well graded gravel or well graded sand, respectively. On the other hand, a soil with either an excess or deficiency of certain sizes, or if most of the grains are of the same size, is classified as either GP or SP, poorly graded gravel or poorly graded sand, respectively. Coarse-grained soils which contain more than 12% material passing the No. 200 sieve and plot above the A-line are classified as GC, clayey gravel, or SC, clayey sand. On the other hand, coarse-grained soils which contain more than 12% material passing the No. 200 sieve and plot below the A-line are classified as GM, silty gravel, or SM, silty sand. Coarse-grained soils which contain between 5% to 12% materials passing the No. 200 sieve are classified with a dual symbol, depending on the gradation characteristics (W or P), the type of fines (M or C), and the soil type (G or S). The soil description associated with a given gravel designation should include *sand* if 15% or more sand is present in the sample. Similarly, sand designation should include *gravel* if the sample contains 15% or more gravel (Al-Khafaji and Andersland 1992).

Fine-grained soils are those having more than 50% passing the No. 200 sieve. They are classified in terms of their consistency characteristics using the plasticity chart developed by Casagrande (1948). The fines are classified as CL, inorganic clay of low plasticity, or CH, inorganic clay of high plasticity if the liquid limit and plasticity index plot above the A-line. On the other hand, they are classified as ML, silt of low plasticity, and MH, silt of high plasticity, if the liquid limit and plasticity index plot below the A-line. The clay, silt, and organic soils are further subdivided based on relatively low (L) or high (H) liquid limits. The dividing line between the low and high liquid limits has been arbitrarily set at 50. Organic soils are classified as OL, organic silt and organic silty clays of low plasticity, or OH, organic clays of medium to high plasticity.

AASHTO Soil Classification System

This system originated from the need to classify soils for highway construction purposes. It was originally developed by the U.S. Bureau of Public Roads in 1929 and then revised several times, with the 1945 revision becoming what is basically today's AASHTO system (Liu and Evett 1992). The system classifies soils into seven groups, A1 through A7. In addition, organic soils are classified into one group, A8. The boundary between the granular materials and silt-clay materials is No. 200 sieve (0.075 mm). Granular materials are those having 35% or less passing the No. 200 sieve and designated A1 to A3, whereas silt-clay materials with more than 35% passing the No. 200 sieve are designated A4 to A7. The classification procedure requires the determination of the percentages passing the No. 10, No. 40, No. 200 sieves, liquid limit, and plasticity index. The procedure proceeds from left to right by the process of elimination until the proper designation is reached. Once the soil is classified, it is further described using a *group index* which utilizes the percentage passing the No. 200 sieve, liquid limit, and plasticity index (Das 1994).

Expansive Soils Classification Systems

Expansive soils swell when given access to water and shrink when they dry out. Consequently, the swelling and shrinkage phenomena cause extensive damage to engineering structures. Soils that are classified as CH, MH, and CL (USCS), and A6 or A7 (AASHTO) can be potentially expansive; therefore, there is a need to classify their swelling potential. Several empirical relationships have been developed for classification purposes based on liquid limit, plastic limit, plasticity index, clay content, activity, etc. Such systems include Holtz and Gibbs (1956), Seed et al. (1962), Dakshanamurthy and Raman (1973), Van der Merwe (1975), Snethen et al. (1977), and Chen (1988). The systems developed by Seed et al. (1962), Dakshanamurthy and Raman (1973), and Van der Merwe (1975) are widely used and they yield good correlation with direct measurement of swell potential. Therefore, these three systems were employed in this paper.

EXPERT SYSTEM FOR SOIL CLASSIFICATION

Expert systems incorporate judgment, experience, rules of thumb, intuition, and other expertise to provide advice for a variety of problems. The basic components of expert systems are a knowledge base (KBS), an inference engine, and a user interface. The knowledge base contains facts, concepts, theories, heuristic methods, and rules which the program uses to search for a solution to the problem. This knowledge is incorporated into the KBS through a knowledge representation scheme called production rules. It consists of IF/THEN statements. For example: A rule that identifies swelling potential, plasticity, and group symbols based on liquid limit (LL) and the calculation of plastic limit (PL) is:

```
Rule 3
    IF      LL>=20
            AND LL<35
            AND PI<(0.73*(LL-20))

THEN        Swelling_Potential  = Low
            Plasticity          = Low
            Group_Symbol        = ML;
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Hence, both the computational capabilities of the expert system shell and its ability to handle symbolic representation were used. The inference engine uses the IF/THEN statements found in the knowledge base to infer logically valid conclusions and to logically justify conclusions at the completion of the program.

The user interface, on the other hand, is a language processor for friendly communications between the user and the computer. To enhance the user interface in the soil classification decision support system, colorful, menu-driven windows were generated using the capabilities of the shell.

DESCRIPTION OF THE DECISION SUPPORT SYSTEM

This expert decision support system application was developed using the VP-Expert rule-based expert system shell by Paperback Software International of Berkeley, CA (1989). The system consists of five different modules or knowledge bases that are linked to the main menu and to each other as shown in the system architecture in Fig. 1.

This decision support system has been developed for classifying soils. The system allows the user with a limited geotechnical background to quickly and accurately identify a given soil and determine its suitability for different types of construction. It can perform mathematical calculations and interpret physical characteristics. The system computes the percentages of gravel and sand from the percentages passing the No. 4 and No. 200 sieves. Furthermore, it determines the type of fines (silt or clay) based on the liquid limit and plastic limit values (using the plasticity chart) or dry strength or dilatancy depending on the availability of data. Based on the different input parameters, the system determines the type of soil,

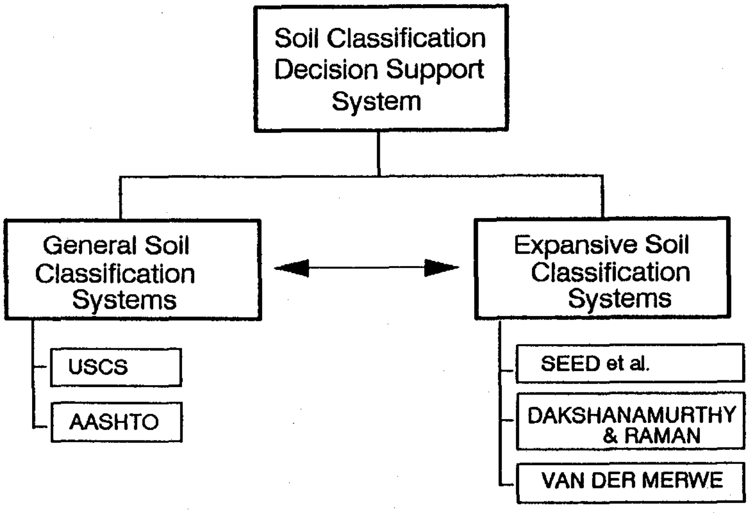

Fig. 1 The soil classification decision support system architecture

group symbol, group name, and description of the soil identified for the USCS; the group symbol and group index value for the AASHTO system; and the swelling potential for the selected expansive soil classification systems. The system doesn't include organic soils since they can be identified visually through their texture, color, and other features.

THE DECISION SUPPORT SYSTEM CONSULTATIONS

The execution of the system starts by welcoming the user and defining the system's objective. The system then provides the user with the necessary definitions and instructions needed to be followed in running the program as shown in Fig. 2. Next, the system displays the main menu as shown in Fig. 3, and asks the user to select the desired classification system needed. The user is required to choose one system from the list shown in Fig. 3. For example, the user should type number 2 if AASHTO is needed to be used. The following problem examples were randomly selected to illustrate the use of the expert system in classifying soils according to the USCS, AASHTO, Seed et al. (1962), Van der Merwe (1975), and Dakshanamurthy and Raman (1973) systems.

To use this system please insure that the following definitions are understood and instructions are followed:

LL= Liquid Limit	- No.4 Sieve = 4.75 mm
PL= Plastic Limit	- No.10 Sieve = 2.00 mm
PI = Plasticity Index=LL-PL	- No.40 Sieve = 0.425 mm
C_U = Uniformity Coefficient	- No.200 Sieve = 0.075 mm
C_C = Curvature Coefficient	

Before Running this DSS, Please make sure to:

1) Run Sieve Analysis 2) Find LL and PI 3) Find C_U and C_C

ENTER to select ? & ENTER for Unknown /Q to QUIT

Fig. 2. The soil classification decision support system instruction

SYSTEM MAIN MENU

Please indicate your choice by typing the appropriate number

1) Use Unified Soil Classification System (USCS)
2) Use AASHTO

Expansive Soils Classification Systems

3) SEED et al. Classification
4) DAKSHANAMURTHY & RAMAN Classification
5) VAN DER MERWE Classification

PRESS ESC TO EXIT PROGRAM

ENTER to select ? & ENTER for Unknown /Q to QUIT

Fig. 3. The soil classification decision support system main menu

The Unified Soil Classification System (USCS)

The first step is to choose the USCS from the systems main menu by typing number 1 as shown in Fig.3. Then the system poses a question to the user about the percentage passing No. 200 sieve for the determination of whether the soil is coarse or fine. Furthermore, it asks about the percentage passing No. 4 sieve in order to determine whether the coarse soil is gravel or sand. Next, the system asks the user to enter the input data in a question and answer manner. In other words, once the user answers question 1, the system proceeds to the next question and so on. In the first question, the system asks the user to enter the percentage passing No. 200 sieve. Then the user enters 8 (Fig. 4.), for example. With this answer, the system classifies the soil with a dual symbol. Next, the system asks about the coefficient of uniformity (C_u) and coefficient of curvature (C_c) which were entered as 3.9 and 2.1, respectively. Based on this answer, the system classifies the soil as *poorly graded sand.* Finally, the system asks about the liquid limit and plasticity index values which were entered as 39 and 8, respectively. With this answer, the system concludes that the soil is SP-SM (*poorly graded sand with silt*) as shown in Fig. 5.

Welcome to the Unifid Soil Classification System: SAND

Please Answer the Following Quastions:

- What Is the percent passed the No. 200 sieve? 8
- What is the C_u value? 3.9
- What is the C_c value? 2.1
- What Is the percent passed the No. 4 sieve? 90
- What is LL value? (Type ? if no value given) 39
- What is PI value? (Type ? if no value given) 8

ENTER to select ? & ENTER for Unknown /Q to QUIT

Fig. 4. Sample consultation from the USCS

Welcome to the Unifid Soil Classification System: SAND

.... *RESULTS OF CONSULTATION* ....

The Type of Soil is: SAND
The Group Symbol is: SP-SM
The Group Name is: POORLY GRADED SAND WITH SILT

ENTER to select ? & ENTER for Unknown /Q to QUIT

Fig. 5. Sample consultation results from the USCS

AASHTO System

The execution of this system starts by first choosing number 2 from the system's main menu as shown in Fig. 3. With this choice, the user enters the AASHTO system. Next, the system asks the user to enter the percentage passing No. 200 sieve. The user then enters an appropriate number such as 38. Based on this answer, the system classifies the soil as *silt-clay material*. Also, the system inquires about the percentages passing No. 40 and No. 10 sieves. However, for this example, these parameters are not needed for classification. Finally, the system inquires about the values of the plasticity index and liquid limit which were entered as 23 and 42, respectively as shown in Fig. 6. With these answers, the system identifies the soil as A-7-6 as indicated in Fig. 7. Furthermore, it determines the group index (GI) for the soil as 3.62. However, this value should be rounded to a whole number.

Seed et al. (1962) System

The Seed et al. (1962) system is entered by typing number 3 in the system's main menu. Then the system asks about the clay fraction (<2μm) and plasticity index from which it calculates the activity. Then the activity and clay fraction are used for the classification. After entering these two parameters, the system displays the soil swelling potential which is shown as *very high*.

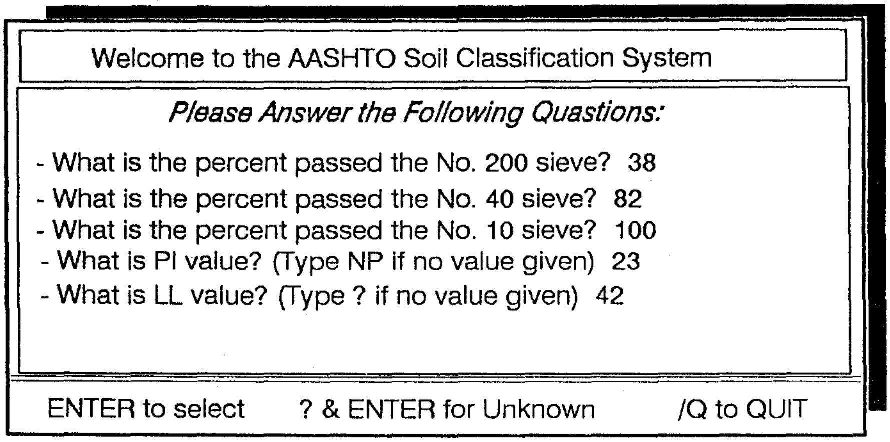

Fig. 6. Sample consultation results from the AASHTO

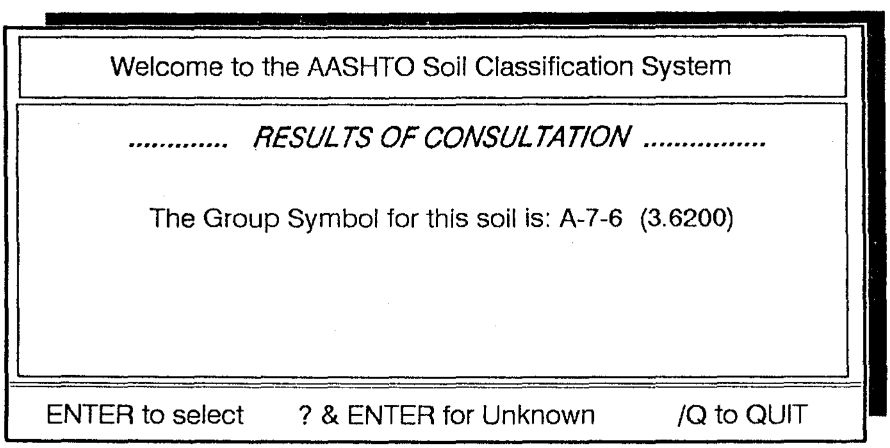

Fig. 7. Sample consultation results from the AASHTO

Dakshanamurthy and Raman (1973) System

The system can be used by choosing number 4 from the system's main menu. Then it inquires about the liquid limit and plasticity index. When the user enters this data, the system displays the classification results. In addition, the system evaluates the soil plasticity.

Van der Merwe (1975) System

This module is started by choosing number 5 from the system's main menu. Then the system asks about the clay fraction and plasticity index in order to classify the swelling potential. When the user enters the data, the system displays the soil swelling potential.

SYSTEM VALIDATION AND VERIFICATION

The validation process of this system consisted of two steps. At the development stage, the system was evaluated and tested using different test cases or examples that were extracted during the knowledge development stage. The purpose of these tests was to ensure the adequacy and accuracy of the knowledge base. It was also to test and establish correct communication among the different system modules. At the user level, the system was validated by an expert in the soil classification area using 25 USCS, 12 AASHTO, and 14 expansive soil random cases. Of the 51 cases tested, the system was capable of classifying 50 examples correctly. Efforts are continuing to further validate the system by other experts in the field to determine its suitability and usefulness.

SUMMARY AND CONCLUSION

An interactive, user-friendly expert system was developed to classify soils according to the USCS, AASHTO, and three selected expansive soil classification systems. Users with a limited geotechnical background can utilize the program to identify soils and their suitability for engineering purposes. The system is very useful for teaching purposes as well as industrial use, particularly when dealing with large amounts of data. It was shown that the program provides quick solutions, and the procedure is simple and easy to follow.

In addition, it should be mentioned here that given the amount of qualitative and quantitative data, the modularity process used in developing this expert decision support system has helped considerably in the testing and validation of the individual knowledge-based modules and in testing the system as a whole.

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