DESIGN OF A HELP TOOL FOR THE EVALUATION OF THE PERMEABILITY OF SATURATED SOIL

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Abstract. The permeability of a soil represents the property of this soil to allow penetration by a fluid, the permeability in the saturated state (ks) of soils is an important parameter to determine before the design of geotechnical works, because it constitutes a factor determining factor in the calculation of the load-bearing capacity of soils. The models for predicting saturated permeability proposed in the literature are numerous (statistical models, empirical models, etc.), and the comparison studies between these models are also numerous; with the aim of facilitating such studies we have attempted to present an expert system which takes care of the evaluation of this parameter based on the methods of (Beyer 1981, Kruger 1992, Terzaghi 1981). Our expert system first allows the calculation of (ks) from the three models studied, as it also allows the comparison between the results of these models on the basis of calculation of the mean square error.

1 Introduction

Permeability, is an important geotechnical property of soil, serves to assess the flow of fluids within soil [5]. The saturated hydraulic conductivity (Ksat) represents a significant factor for characterizing soil permeability, as emphasized by [4]. for the interest that this parameter represents in the field of geotechnics, researchers have developed several methods to determine it in laboratories or in situ. And for its estimation, various mathematical models have been established by several authors and in different periods.
Among these models, the empirical functions of (Beyer 1981, Kruger 1992, Terzaghi 1981), which have proven their effectiveness in several cases, and which remain among the most popular. Given their simplicity and the fact that they are easily implemented on the Python expert systems generator, we chose them for the development of our expert system.
Consequently, the expert system developed as part of this study allows the evaluation of the permeability of soils in the saturation state (ks) on the development environment of Tkinter expert systems which makes it possible to write applications in an environment graphics at a high level via the Python language.

2 Definition of Expert System

Expert systems (ES) fall under the broader domain of artificial intelligence (AI), employing a symbolic approach to representing knowledge, and simulate the process that experts use when they solve problems. In order to understand what ES are and how they work, it is essential to introduce some basic concepts on expertise and what makes an expert an expert.
Experts are individuals who have a high level of skill, knowledge, and experience in a particular field or domain. They are able to solve complex problems efficiently and effectively, often relying on intuition and pattern recognition developed through years of practice.[5]
What sets experts apart from novices is their ability to quickly identify key features of a problem, apply relevant knowledge and experience, and make informed decisions based on this understanding. This process is often subconscious, making it challenging to articulate the reasoning behind their actions.
In the context of ES, this expert problem-solving process is codified into a set of rules and procedures that can be applied to new problems in the domain. ES are designed to mimic the decision-making process of human experts, using a knowledge base to store domain-specific information and an inference engine to apply this knowledge to new problems.
By capturing the expertise of human experts in a formalized way, ES can provide valuable insights and recommendations in a variety of fields, from medical diagnosis to financial planning. They can also be used to train novices by providing explanations for their recommendations, helping them develop their own expertise over time.

3 Development and improvement of ES

Developing an expert system (ES) involves several key steps. Firstly, it is essential to consult one or more human

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experts in a specific field to gather their knowledge. This knowledge is then formalized into a set of rules The management of this knowledge involves various methods and techniques, including perception, identification, analysis, organization, and Once a comprehensive set of rules is established, the ES can apply them to new problems in the domain. This mimics the decision-making process of human experts, allowing the system to provide valuable insights and recommendations.

In addition to rule-based knowledge, ES may also incorporate other forms of knowledge representation, such as case-based reasoning or neural networks, to enhance their problem-solving capabilities. These additional approaches can further improve the system's ability to handle complex and dynamic environments.

Overall, the development of an ES requires a deep understanding of both the domain in question and the principles of AI. By effectively capturing and utilizing expert knowledge, ES can provide valuable support in a wide range of fields, from healthcare to finance to engineering.

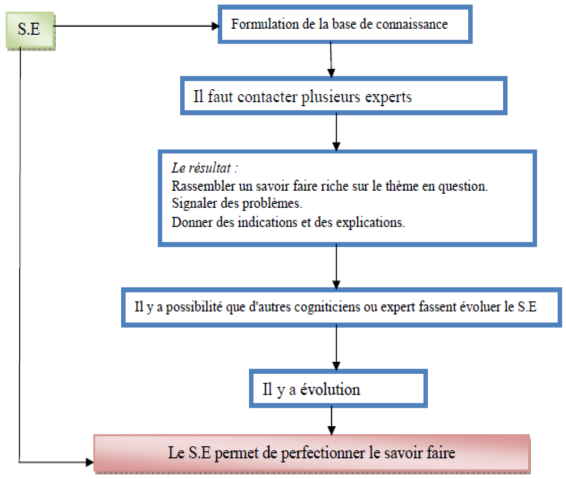

Fig. 1. Process of development and improvement of SE.

3.1 The main components of an expert system

The expert system typically comprises three distinct yet interdependent modules:

Rule Base (or Knowledge Base): This module contains domain knowledge stored in the form of production rules. These rules are created by experts, sometimes with the assistance of cognitive scientists who specialize in knowledge representation.

Inference Engine: The inference engine is the program that utilizes the knowledge stored in the rule base to make decisions or provide recommendations. It applies logical reasoning to derive new information from the existing knowledge base.

User Interface: This module enables users to interact with the expert system. It provides a means for users to input queries or receive responses from the system in a user-friendly manner.

Python boasts a vast standard library and a thriving ecosystem of third-party packages contributed by its active community. This wealth of resources makes

that represent the expertise of these individuals.

memorization. These processes ensure that the knowledge is captured accurately and can be effectively utilized by the ES.

Additionally, there is another component known as the Fact Base, which serves as working memory for the expert system. This is where temporary information is stored during the reasoning process.

Expert system is a complex software system that combines these modules to emulate the problem-solving capabilities of human experts in a specific domain.

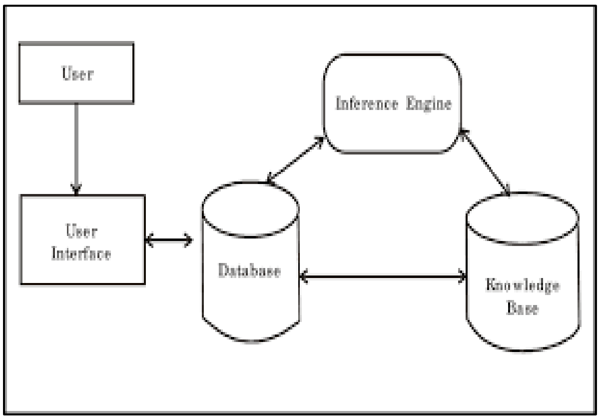

Fig. 2 . Basic structure of ES.

3.2 Python Presentation

The Python language is an interpreted object programming language. It was developed by Guido Von Rossum in 1989 at the University of Amsterdam. This language was named thus in reference to the TV series Monthy Python's Flying Circus [7].

Python is an interpreted, high-level, general-purpose programming language renowned for its readability and simplicity. Guido van Rossum created Python, releasing its first version in 1991. The language's design emphasizes code clarity, with a syntax that allows developers to express concepts concisely and clearly.

A distinctive feature of Python is its use of indentation to define code blocks, rather than relying on traditional symbols like curly braces. This approach, combined with its straightforward syntax, makes Python particularly accessible to novice programmers [7].

Python supports multiple programming paradigms, including procedural, object-oriented, and functional programming. It features a dynamic type system and automatic memory management, which help reduce complexity and minimize errors in programming tasks [7].

Python suitable for a wide array of applications, including web development, data science, machine learning, and more. [7]

Python's simplicity, readability, and versatility have cemented its position as one of the most widely used programming languages, appealing to developers across various industries and skill levels.

4 Saturated permeability estimating

4.1 In laboratory settings

several tests are commonly employed to estimate the saturated permeability of soils:
Constant Head Permeability Test: This test involves allowing water to flow through a soil sample under a constant head. The flow rate is measured to determine the permeability.
Falling Head Permeability Test: Here, water flows through a soil sample from a standpipe. The time taken for the water level in the standpipe to fall by a specified amount is recorded to calculate permeability using Darcy's law.
Variable Head Permeability Test: Similar to the constant head test, but the head of water is varied to establish the relationship between head and flow rate, aiding in permeability calculation.
Rowe Cell Permeability Test: Designed for very low permeability soils, this test involves placing a soil sample in a specialized cell and applying a hydraulic gradient to measure the flow rate and determine permeability.
Pressure Plate Test: While primarily used to determine the soil water characteristic curve, this test can also indirectly estimate permeability by measuring water flow rates at different water potentials.
Centrifuge Permeability Test: By subjecting a soil sample to high centrifugal forces while allowing water flow, this test measures flow rates to calculate permeability.

4.2 In-situ tests for estimating saturated permeability

In-situ tests for estimating saturated permeability of soils include:
Pumping Test: In this test, water is pumped into or out of a well, and the resulting changes in water level are monitored in nearby observation wells. The rate of change in water level is used to calculate the hydraulic conductivity of the surrounding soil.
Slug Test: A known volume of water is rapidly added or removed from a well, and the subsequent response of the water level is measured. This test can provide an estimate of the hydraulic conductivity of the surrounding soil.
Pressure Infiltrometer Test: This test involves applying a known pressure to the soil surface and measuring the rate at which water infiltrates into the soil. The infiltration rate is used to calculate the saturated hydraulic conductivity of the soil.
Borehole Permeability Test: This test involves sealing off a section of a borehole and pressurizing it with water. The rate at which water leaks out of the sealed section is measured and used to calculate the permeability of the surrounding soil.
Double-Ring Infiltrometer Test: This test involves placing two rings of known dimensions on the soil surface, filling the inner ring with water, and measuring the rate at which water infiltrates into the soil. The infiltration rate is used to calculate the saturated hydraulic conductivity of the soil.

4.3 Numerical models

Numerical models are widely used in academia to estimate saturated permeability in complex geological settings where analytical solutions are impractical. Some common numerical models include:
Finite Element Method (FEM): FEM is a numerical technique employed to solve problems in engineering and mathematical physics. It can simulate fluid flow through porous media, aiding in the estimation of permeability.
Finite Difference Method (FDM): FDM is another numerical approach used to solve differential equations. It can be applied to simulate fluid flow through porous media and estimate permeability.
Lattice Boltzmann Method (LBM): LBM is a newer numerical method suitable for modeling complex, multi-phase flows in porous media. It can be utilized to estimate permeability.
Discrete Element Method (DEM): DEM is a numerical technique used to model granular material behavior. It can simulate fluid flow through granular soils, providing estimates of permeability.
Multiphase Flow Models: These models simulate the flow of multiple fluid phases (e.g., water and air) through porous media, offering insights into permeability under different conditions.
Computational Fluid Dynamics (CFD): CFD is used to solve fluid flow problems, including those in porous media. It can help estimate permeability and understand fluid behavior in complex geological formations.
These numerical models are valuable tools for estimating saturated permeability in challenging geological environments, aiding researchers and engineers in understanding and predicting fluid flow in porous media.
An example of an existing expert system that calculates soil permeability is the "SINTEF Pore Pressure Toolbox," developed by SINTEF, a research institute based in Norway. This software is designed to assess soil behavior in terms of interstitial pressure and permeability, utilizing various methods and models, including approaches for both saturated and unsaturated soils. It incorporates laboratory data as well as in situ data to estimate soil permeability under various conditions.

5 Presentation of the different models

5.1 Terzaghi model (1981)

Terzaghi's model for saturated permeability estimation, as described in his seminal work in 1981, is an empirical approach used in geotechnical engineering to predict the hydraulic conductivity of saturated soils. This model is based on Terzaghi's extensive research and observations in soil mechanics.

$$ks(m/s) = 200\ e^2\ d_{10}^2 \qquad (1)$$

d_e : effective grain size diameter ;
e: void ratio.

Terzaghi's model assumes that the hydraulic conductivity of saturated soils is influenced by the soil's void ratio, which is in turn influenced by the effective vertical stress.
It's important to note that while Terzaghi's model provides a useful framework for estimating saturated permeability in geotechnical practice, it is based on empirical relationships and may not accurately capture the complex behavior of all soils in all conditions. Additional site-specific testing and analysis may be required for more accurate permeability estimations in practical applications.

5.2 Beyer model (1981)

The Beyer model (1981), is an empirical formula used to estimate the saturated hydraulic conductivity (permeability) of soils, particularly for coarse-grained soils. The Beyer model provides a simple and convenient method for estimating permeability based on grain size distribution. However, its accuracy may vary depending on the soil type and conditions, and it is most reliable for coarse-grained soils.The model is expressed as:

$$ks= Cd_e^2 \qquad (2)$$

$$C=4.510^{-3}\log\left(\frac{500}{d_{60}/d_{10}}\right) \qquad (3)$$

d_e : effective grain size diameter ;
d_{10}, d_{20} : grain size distribution ;

5.3 Kruger model (1992)

The Kruger model (1992), is an empirical formula used to estimate the saturated hydraulic conductivity (permeability) of soils based on grain size distribution. The model is particularly applicable to sands and gravels. The Kruger model provides a simple and practical approach to estimating permeability based on grain size information. However, like other empirical models, its accuracy may vary depending on the soil type and specific conditions.

$$ks(m/day) = 240\ \frac{n}{(1-n)^2}\ d_e^2 \qquad (4)$$

n: porosity;
d_e: effective grain size diameter;

6 Structuring knowledge

In the design process of our expert system for evaluating the permeability of saturated soils using empirical models, the analysis of know-how is crucial as it forms the foundation for selecting a mode of representation for this expertise. We have chosen to structure the knowledge base with objects and classes, which allows for a systematic organization of the information. Production rules are also utilized to formalize operational knowledge, enabling the system to make decisions based on the input data.
The nature of our expert system necessitates several classes of objects, which are organized under the general diagram in Figure 4:
Layer: Represents a layer of soil for which the permeability is being evaluated. This class may include attributes such as soil type, thickness, and other relevant properties.
Site: Represents the location or site where the soil layers are present. This class may include attributes such as geographical coordinates, climate data, and other site-specific information.
Ks: Represents the saturated hydraulic conductivity (Ks) of the soil layer, which is a key parameter in the evaluation of permeability. This class may include attributes such as the Ks value and the method used for its estimation.
Laboratory Data: Represents the data obtained from laboratory tests conducted on soil samples. This class may include attributes such as test results, sample properties, and testing methods.
continue: Represents a continuation of the analysis or process flow within the expert system. This class may include attributes or methods related to the continuation of the evaluation process.

By structuring the knowledge base with these classes of objects and utilizing production rules, our expert system will be able to effectively evaluate the permeability of saturated soils using empirical models, providing valuable insights for geotechnical engineering applications.

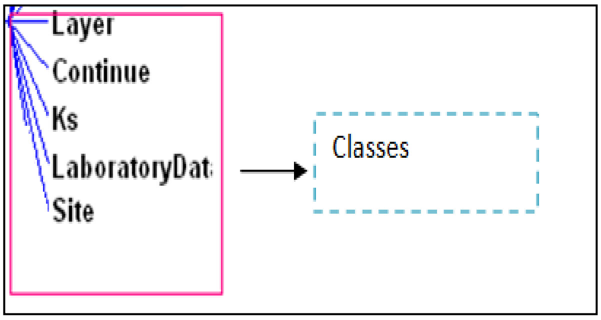

Fig. 3 . Inheritance graph of classes and objects of the expert system developed

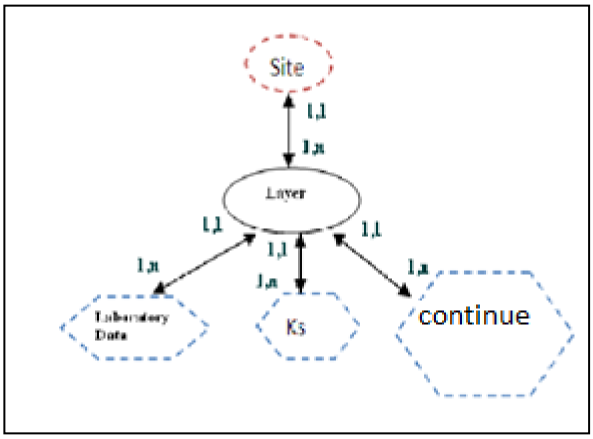

Fig. 4. conceptual diagram of the object base of our SE

In our expert system, the site investigation process involves conducting drilling wells on a site, with each well identifying a specific layer for testing. For each layer, we determine the necessary parameters for the equations of Beyer (1981), Kruger (1992), and Terzaghi (1981), which are used to estimate the permeability in the saturated state (Ks) based on laboratory data.

Each "Site" object class is connected to the "Layer" object class through the "investigation layer number" attribute. This connection allows us to associate each layer with the site it belongs to. Similarly, each "Layer" object class is linked to the "Site" object class through the "site name" attribute, facilitating the connection between layers and sites. Additionally, each "LaboratoryData" and "Ks" object class is linked to the "Layer" object class through the "Investigation layer number" attribute, enabling us to associate laboratory data and permeability values with specific layers.

The user interface of our expert system allows users to input the results of laboratory or in situ tests. It also provides them with the estimated permeability of the soil using the formulas of Beyer (1981), Kruger (1992), and Terzaghi (1981). Furthermore, the interface allows users to compare the results obtained from these formulas, providing them with valuable insights for their geotechnical engineering projects.

Fig. 5 . User interface of our expert system

7 Discussion

In developing an expert system for evaluating the permeability of saturated soils using empirical models, several key considerations and implications arise:

Methodological Approach: The utilization of empirical models, particularly those proposed by Beyer (1981), Kruger (1992), and Terzaghi (1981), reflects a pragmatic approach to soil permeability estimation. These models, rooted in established geotechnical principles, provide a reliable basis for permeability evaluation in practical engineering applications.

Knowledge Representation: The decision to structure the knowledge base using objects and classes is pivotal for systematic knowledge organization. This approach allows for the efficient storage and retrieval of information, ensuring that the expert system can effectively utilize and update its knowledge base.

Integration of Laboratory and Field Data: The expert system's ability to link laboratory data and in situ test results with specific soil layers enhances its practical utility. This integration enables engineers to make informed decisions based on comprehensive and site-specific information, thereby improving the accuracy of permeability estimations.

User Interface Design: The user interface's functionality, enabling users to input test results and receive estimated permeability values, enhances the system's accessibility and usability. This feature is crucial for ensuring that the system can be effectively utilized by practitioners with varying levels of expertise in geotechnical engineering.

Future Development: While the current system represents a significant advancement in soil permeability evaluation, there is scope for further refinement and expansion. Future developments could focus on enhancing the system's accuracy, incorporating additional empirical models, and improving its adaptability to diverse geotechnical contexts.

Then, the development of an expert system for evaluating the permeability of saturated soils using empirical models represents a valuable contribution to geotechnical engineering.

This work has the potential to significantly impact the field by providing engineers with a practical and efficient tool for soil permeability estimation in various engineering projects.

8 Conclusion

The development of an expert system for evaluating the permeability of saturated soils using empirical models represents a notable advancement in geotechnical engineering. The application of established models by Beyer (1981), Kruger (1992), and Terzaghi (1981) offers a practical and dependable method for estimating soil permeability.

The structured knowledge base, employing objects and classes, ensures systematic organization and efficient utilization of information within the expert system. This, combined with the integration of laboratory and field data for specific soil layers, enhances the system's practical utility and accuracy in permeability estimation.

The user-friendly interface further enhances accessibility and usability, making the expert system accessible to practitioners with varying levels of expertise. Future developments could focus on refining the system's accuracy, incorporating additional empirical models, and enhancing its adaptability to diverse geotechnical contexts.

Overall, this work has the potential to significantly impact geotechnical engineering practice by providing engineers with a valuable tool for informed decision-making in soil permeability evaluation for various engineering projects.

References

1. N. Duclosson. Cours IA - Systèmes à bases de règles Systèmes experts, https://perso.liris.cnrs.fr/alain.mille/enseignements/DEAECD/site_ia_emiage/session1/syst%E8mes_experts.htm
2. M. Malek. Systèmes experts, notes de cours. Cycle ingénieur - Deuxième année département systèmes informatiques formels & intelligents (2008), file:///C:/Users/badre/Downloads/SYST%C3%88MES%20EXPERTS%20-%20Notes%20de%20cours.pdf
3. F. Kabanza. Intelligence Artificielle IFT61 : Systèmes experts, Université de Sherbrooke, https://plandecours.dinf.usherbrooke.ca/pdc/2022-2/IFT615/0/
4. J. Chen, el al. Developmental co-exposure of TBBPA and titanium dioxide nanoparticle induced behavioral deficits in larval zebrafish. Ecotoxicology and Environmental Safety. **215**, (2021), https://doi.org/10.1016/j.ecoenv.2021.112176
5. R.P. Chapuis. (2012). Estimating the in situ porosity of sandy soils sampled in boreholes. Engineering Geology, **141-142**, 57-64 (2012)
6. https://www.w3schools.com/python/
7. N. FAURE. Représentation des connaissances géotechniques, cours Université Jean. Moulin – Lyon 3, https://liris.cnrs.fr/inforsid/sites/default/files/a585c1dH6Ve5TRdOw.pdf
8. D.G. Fredlund and A. Xing. Equation for the soil–water characteristic curve. Can. Geotech. **31**(4), (1994), https://doi.org/10.1139/t94-06