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Development of a New Equipment to Measure the Hydraulic Conductivity of Clay Liners to Facilitate Construction and Maintenance of Structures with Compacted Clay.

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Abstract:

It is proposed to develop an instrument (permeameter) that will measure the coefficient of permeability (hydraulic conductivity) of soil based on the water content and dry-unit weight of the soil. The proposed instrument will be smaller than current equipment and portable (possibly pocket-size); it will measure permeability faster than the current methods and equipment used in the lab or the field with equal consistency and accuracy. Due to its size, it will be more advantageous in the field because it will be easier to carry.

Background

The idea for this instrument is the result of a formula developed from a doctoral dissertation that predicts the permeability of clay liners or compacted clay [1, 2]. The best reason for developing such an instrument for measuring permeability is that, the formula for predicting permeability is based on compacted clay properties that highly affect the permeability of the soil; these are water content and dry unit weight of the compacted clay [1, 2, 6, 7]. Permeability is the movement of a fluid (if the fluid is water, permeability is referred to as the hydraulic conductivity) through the pores or voids of the soil. Both dry unit weight and water content of the soil are indications of the amount of voids in the soil for the flow of water from one point to the other.

The established Model WD is a function of the water content and the dry unit weight. By definition,

$$W = \frac{W_w}{W_s} = \frac{\gamma_w V_w}{\gamma_s V_s} = \frac{\rho_w V_w}{\rho_s V_s} \qquad (1)$$

where W = water content,
W_s = weight of solids,
W_w = weight of water,
γ_s = the unit weight of the soil solids (particles),
ρ_s = density of the soil solids,
and ρ_w = the density of water.

The dry unit weight is also by definition,

$$D = \frac{W_s}{V} = \frac{\rho_s g V_s}{V_s + V_w + V_a} \tag{2}$$

where D = the dry unit weight of the soil
V = the total volume of the soil (including air and water)
V_a = the volume of air in the soil
V_w = the volume of water in the soil
V_s = the volume of soil solids in the soil
and g = acceleration due to gravity.

The Model WD ($K = e^{(4.94 - 0.38\,W - 1.21\,D)}$) can be stated, mathematically, as:

$$K = f(W, D) \tag{3}$$

where K = the hydraulic conductivity estimated by Model WD.
From Equations 1, 2, and 3,

$$K = h(V_s, V_a, V_w, g, \gamma_w, \gamma_s) \tag{4}$$

but,

$$S = \frac{V_w}{V_v} = \frac{V_w}{eV_s} \tag{5}$$

and from Equation 5,

$$V_w = SeV_s \tag{6}$$

where V_v = is volume of voids.
e = is the void ratio of the soil
and S = the degree of saturation
Therefore, Equation 4 can be rewritten as,

$$K = p(V_a, S, e, V_s, g, \gamma_w, \gamma_s) \tag{7}$$

which means, K is a function of the volume of air, degree of saturation, volume of solids, void ratio, acceleration due to gravity, unit weight of water and unit weight of solids. The problem with Equation 4 is that most of the independent variables are, in fact, dependent, as can be observed in Equation 6. The mathematical relationships of the interdependencies of the variables in Equation 4 have been well established in the literature [3, 4] and need not be rehashed here. Thus, the reduction of the number of variables for deriving a predictive model employing mathematical and/or experimental methods would eliminate the number of error terms. For example, if all the variables in Equation 7 are used, there would be seven error terms to deal with. The error component would worsen if any of the variables in Equation 7 had an order of magnitude above one. If the equation is derived using statistical procedures, then there will be a higher level of confounding which could result in unstable models. Incidentally, the established model to be used was developed through statistical analysis using published data in a refereed journal [1, 2].

Structure of Instrument

Figure 1 is a schematic drawing of the instrument (permeameter) showing the three main units:

- A water content measuring unit
- A dry-unit weight measuring unit and
- A computation unit where the formula will be applied.

Other accessories include the following:

- LED display window(s) which will display the:
  - Water content,
  - Dry-unit weight and
  - Computed permeability.
- A color coded indicator which will indicate whether the permeability measured is acceptable or unacceptable.

The color will be displayed simultaneously or alternately with the permeability in the LED display window. The acceptable permeability, as required by United States Federal Regulations is 10^{-9} m/s.

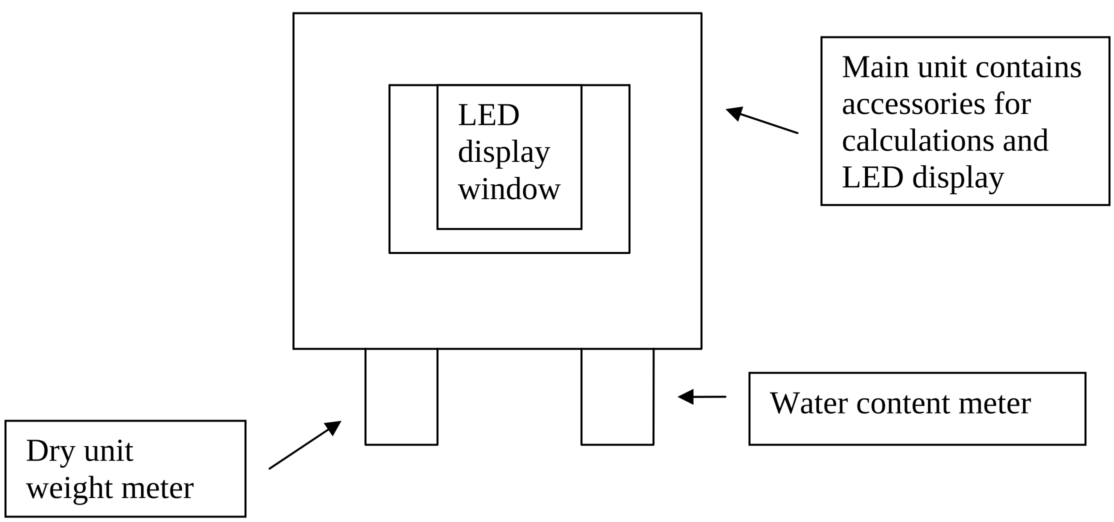

Figure 1: Schematic Drawing of Permeameter

Significance of Instrument:

As mentioned in the abstract, the application of the knowledge of permeability (hydraulic conductivity) is wide. It is used in the construction, use, and monitoring of small and large civil engineered structures, such as dams, roads, highways, foundations, airports, lagoons and other water detention units. For example, buildings will collapse, sink, or fall out of plumb (fail, as is technically described) if the foundation is subject to an unexpected intake of water as a result of higher coefficient of permeability in the foundation soil.

To date, in the era of technology and micro-instruments, there is no known smaller and faster instrument for detecting the permeability of soil, neither in the lab nor in the field. Most of the methods currently available consist of several cumbersome steps and stages that take days to be completed. Two of these instruments are: The Boutwell permeameter and Constant Head Borehole permeameter. Others are the Air Entry Permeameter, the Ponded Infiltrometer and the Tension Infiltrometer, which use infiltrometer methods, and the Troxler 3440 Gauge which uses nuclear technology. The use of the Troxler 3440 Gauge may require skilled training and ultimately be dangerous to users' health. All of the instruments mentioned are good for field use only and normally on saturated soils [3, 4, 5]. The invention of the proposed instrument will have the following effects:

- Hasten construction of the structures as a result of the faster method for measuring permeability
- Allow proper quality control of constructed structures, because the permeability of the soil used in the structures could be monitored in construction stages
- Allow monitoring of the performance of the constructed units by using the instrument as a sensor.

The monitoring units will indicate when the attenuating capabilities of the compacted clay have deteriorated, thus, making failure of the structure imminent. In structures such as dams and other earthen water barriers, early warning could lead to the prevention of catastrophes, such as loss of human life and property.

It is anticipated that the Departments of Defense, Energy, Environmental Protection Agency (EPA), Transportation, the Army Corps of Engineers, and Education will be interested in this type of device. For example, the problem of settlement (which is the result of water movement in the foundation soil) will be eliminated because of proper quality construction. Should the quality of the soil deteriorate in terms of its permeability, the monitoring system will alert authorities, and measures could be taken to arrest problems with settlement, which cause wall and floor cracks and even building collapse.

In transportation, warping roads and pot holes, due to permeability of water could be eliminated if the sub-grade construction is monitored during and after construction using the instrument. If road sections, susceptible to high permeability or early deterioration of compacted soil, are monitored with the instrument, this will lead to timely maintenance of the sections, avoiding the ugly specter of potholes and warped, bumpy road sections. Eliminating these problems, in the roadway construction industry, will prevent road accidents and save lives. Similarly, problems may be avoided in parking lots and airport pavements by using the instrument as is suggested for roadway construction.

Countless lives (human and animal) and valued real estate property have been lost when a water containment barrier with earthen dams or levees suddenly gives way due to saturation of the compacted soil, which is the result of high permeability. If the proposed instrument is used in quality control during the construction of a water containment structure and the performance of such structure is monitored with the instrument, a sudden failure could be averted. In this case, the indicators on the instrument will alert authorities to notify residents of imminent danger and advise them to evacuate the area, saving lives and property.

Using the proposed instrument in constructing and monitoring landfills or underground structures holding harmful waste will prevent the pollution of precious underground resources, notably potable water in aquifers. This will help eliminate diseases resulting from unknowingly using water contaminated by harmful leachates from landfills and other underground waste containment structures. Soil contamination will also be prevented from hazardous leachates. If the contaminant is volatile, destruction to human life could be significant, because as soon as it gets into soil, it evaporates and fills the atmosphere, which makes it easily inhaled and puts lives in that vicinity at risk.

Conclusion:

The movement of water in soils poses a myriad of problems in the construction, maintenance and monitoring for failure of civil engineered structures such as: building foundations, dams, embankments, airfield pavements, landfills, underground radioactive toxic water waste containment units, irrigation channels, drainage ponds, grazing ponds, and retaining walls. Thus, there is a vast existing market from all industries involved in the construction, maintenance, and use of the above facilities for permeability measuring instruments. Some of the existing instruments require extensive training and certification to be used, due to the numerous components of the instruments. The industry will welcome a smaller and faster permeameter with monitoring capabilities, which can be used in the lab and the field. Using the proposed permeameter will be cheaper because, virtually, no training will be required for its use. Permeability is widely studied in colleges, universities, and technical schools around the world, so there is also a market in education.

References

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Biography

Frank Atuahene is an Assistant Professor at Georgia Southern University in Statesboro, Georgia. He has experience in construction project management, higher education instruction, road design and environmental consulting in Ghana and the United States. He has advanced degrees in structural, industrial and geotechnical engineering.