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The Improvement of Triaxial Apparatus for Thermo-Hydro-Mechanical Behavior of Soils at Elevated Temperatures

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ABSTRACT

The need for thermo-hydro-mechanical studies of soils at high temperatures has increased in environmental geomechanics these years. An important case is the behavior of engineering clay barrier or natural host rock in deep nuclear waste repositories that undergo high temperatures up to 120°C. Only an apparatus designed for high temperatures can do this kind of studies. This research reviews design, assemble and calibration of a triaxial set that has been made for the first time in Iran. Triaxial tests at high temperatures indicated that sand-bentonite with unit weight in the range of density for engineering barrier of nuclear waste repositories, has contractive behavior. When this mixture was heat up to 110°C, both peak and critical state shearing strength reduced about 20 percent and critical state friction angle decreased too. These results were similar to other authors' results that show the apparatus has worked conveniently.

KEYWORDS

Thermo-Hydro-Mechanical Behavior of Soils; Triaxial Test Apparatus; Elevated Temperature.

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1- INTRODUCTION

Changes in temperature occur in many geotechnical engineering problems, but the effects of these changes on the engineering behavior of soils and rocks is one of the most important subjects in geotechnical engineering, especially in the field of environmental geomechanics. One of these studies included investigations of the effect of temperature on different parts of layers around waste canisters such as soil engineering barriers (e.g., bentonite) or on host rocks or soils and their boundary interfaces.

One of the most important challenges in this kind of study is in developing experimental apparatuses that are capable of producing and controlling high temperatures. In hydro-mechanical studies of soils, triaxial tests provide the best-known and most practical tool for geotechnical researchers, but triaxial test apparatuses can typically only function at temperatures of up to 50˚C. Consequently, the need to design and produce triaxial apparatuses that are capable of reaching high temperatures is a necessity for thermo-mechanical studies in geotechnics.

2- METHODOLOGY, DISCUSSION, RESULTS

The main problem of triaxial set at elevated temperatures was limitation for heating up to higher temperatures as the result of limitation of different parts -except cell that usually made for high temperature- such as pressure controllers, transducers etc. at high temperature. To produce temperatures of up to 120°C, the circulating fluid was changed to avoid evaporation, and the water was rapidly cooled in order to prevent hot water exited from the cell, from entering into other parts of the system (Figure 1).

The system that produces, controls and measures temperature consists of a digital oily thermal bath to heat the fluid up to a given temperature and to circulate hot oil in heater circuit inside the cell around the sample. A vacuum circulating pump is used to transfer oil from the bath to the circulating spiral pipes. The highest attainable temperature in the bath is 120±0.1°C, and water, silicone oil or hydraulic oil with viscosity of up to 10cSt can be used in this bath. Producing heat from a thermal bath allows heat to be transferred to the water inside the cell by a spiral pipe made from stainless steel with a diameter of 8 mm. The upper part of this pipe protrudes out of the cell and is connected to a hot oil hose by a fast fit connector that is 6 mm in diameter. This pipe and hose have a temperature and pressure tolerance of 200°C and 3.5 MPa, respectively. Temperatures are read by two PT100 thermocouples made by Extreme^{TM} is used for temperature range -200°C to 550°C that are located within 4 mm of the samples on two brackets, and their data are sent to a data logger with an accuracy of ±0.1 °C.

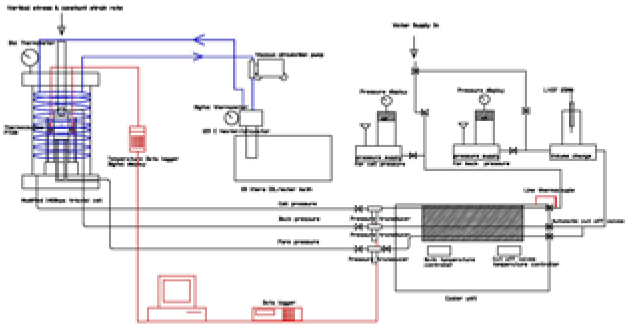

Figure 1. Triaxial apparatus that can control temperatures up to 120°C

The cooling system used to protect sensitive instruments from heat is a cooling bath that is cooled using a fridge condenser. Copper pipes that connect cell pipes to the pressure system are located inside of this bath. A circulating submerged pump unifies the temperature in the bath. Three electronic cut-off valves are attached to this system to prevent water with a higher temperature than the allowable limit from exiting the system and affecting the compressors and the volume change gauge. This temperature can be adjusted by the user. In our system, a temperature of 50°C was used. A digital controller allows the temperature of the cooling bath to be adjusted.

The triaxial cell with a temperature tolerance of 120 °C is made of aluminum and is protected by ten vertical screws. The wall of the cell is made of Perspex with a 25 mm thickness. To strengthen the cell at high temperatures and limit its deformations, a steel plate guard with a 1 mm thickness is attached onto the Perspex wall and is fixed stiffly using three screws. A refractory filler layer is located between these two layers to distribute stress from the inner layer uniformly onto the guard layer and insulate the cell. A thermometer is installed on the top cap of the cell in order to monitor the temperature of water inside of the cell. Two windows with a diameter of 40 mm were prepared on the cell to check inside the cell and the state of the sample. O-rings in interfaces and around the sample are made of silicone rubber and are resistant up to 130°C.

A series of Consolidated Undrained triaxial tests were conducted using the above-mentioned apparatus on a 1:1 sand-bentonite mixture. These tests were carried out in two stages: first by consolidation (or swelling) in a 600 kPa confining pressure at a given temperature and then by shearing the specimen at undrained condition with constant temperature and confine pressure. The temperature and confining pressure were increased simultaneously at a rate of 5°C/hr.

An increase in temperature causes a decrease in the surface potential for a constant surface charge. Thus, the particles come closer to each other at higher temperatures than at lower temperatures and the amount of absorbed water in the microstructure of the clay decreases.

After the swelling was equalized, the specimen was sheared at a predefined rate. The samples failed in a ductile manner with a slight strain softening. The peak strength was achieved at a strain of approximately 5%; however, shearing continued and reached a value of approximately 15% axial strain to reach the critical state condition. The results showed the decrease in the peak strength and the critical state strength. The increasing the temperature from 25 up to 110°C caused a decrease in the peak strength of the sand-bentonite mixture of approximately 20%. This decrease in strength should be considered when designing the engineering layers in nuclear waste repositories. The variation of pore pressure is greater at higher temperatures. The behavior of the sample at higher temperatures was contractive, while at lower temperatures, the sample was first contractive and then dilative.

3- CONCLUSIONS

This paper reviewed the different methods of producing a triaxial apparatus with temperature control and the different design features of these apparatuses. By comparison, heating using a circulating fluid was selected as the most appropriate method to create a uniform thermal field.

By inserting a cooling device into the high temperature triaxial setup, it was possible to reach temperatures of up to 120°C in cell and soil samples without using compressors or volume change device that are tolerant to high temperatures. The use of hydraulic oil allows samples to be heated in short periods of time.

A series CU triaxial test on a 1:1 sand-bentonite mixture shows that, when temperature is increased from 25 up to 110°C, the peak strength of the sample decreases by approximately 20%. A strain softening behavior is evident in the stress-strain diagram of this mixture. The material contracts upon shearing at higher temperatures, while at lower temperatures it first contracts and then dilates.

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