A Comparative Analysis on Tensiometer Structured Suction Handle System for Lab Testing Of Unsaturated Soils

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Abstract – This paper exhibits the improvement of an automated Tensiometer based suction control system for testing unsaturated soil tests. The system has the ability to dry and wet soil, while measuring suction (pore water pressure – air pressure) and water content. The system utilization air flow inside a shut circle to dry the dirt, or water infusion to wet the dirt, to accomplish the obliged pore water pressure while the air pressure is kept climatic. Pore water pressure is controlled by utilizing a sentiment computer system that dries or wets soil specimens consistent with estimations got from specimen mounted high suction Tensiometer. Overabundance moisture buzzing around flow circle is caught by an in-line moisture trap comprising of a fixed unit holding a desiccant (silica gel), which is set on an electronic balance to give nonstop estimations of held water. Progressions of the specimen water substance are measured as the distinction between the measure of water infused and that held by the moisture trap. The system is completely automated and runs controlled by software with least aid. The proposed suction control system presents points of interest over the routine pivot interpretation system as it dodges the necessity for hoisted pore air pressures and henceforth better repeats the regular courses of action of wetting and drying of soils. The system was produced for utilization in a triaxial unit, however could likewise be utilized with different instruments and for the determination of water maintenance curves.

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INTRODUCTION

The predominant Tensiometer based suction control system for triaxial testing of unsaturated soils was presented by Cunningham (2000) and later emulated by Jotisankasa (2005). In these systems, suction (pore water pressure – air pressure) is controlled by changing water pressure while keeping the air pressure near barometrical quality, in this way maintaining a strategic distance from the necessity for raised air pressures as in the pivot interpretation system. This better recreates common drying or wetting courses of action in the field and permits cavitation inside soil pores, which might rather be averted by the pivot interpretation procedure. Testing is restricted to the tensiometer‟s estimation run (2mpa) however this is fitting for numerous farming and building provisions. As examination advances towards more accurate, dependable and vigorous tensiometer plans, the utilization of these tests is liable to get regular spot for the measurement/control of pore water pressure and could revolutionise unsaturated soil testing.

In the system introduced by Cunningham (2000) and Cunningham et al. (2003), the dirt was dried in a controlled way by circling air through the base of the specimen while, at the same time, measuring pore water pressure with two tensiometers at the side and top of the example. Assuming that pore water pressure was higher than the target esteem (e.g. -100kpa being the target esteem -150kpa), the control software reacted by expanding air pressure, which immediately opened an in-line spring valve with the goal that drying of the dirt could occur. In the event that pore water pressure was more level than the target esteem (e.g. -200kpa being the target esteem -150kpa), the system diminished the air pressure, which shut the spring valve and quit drying.

The air flow method proposed by Cunningham (2000) endeavors moisture evaporation to control pore water pressure. Nonetheless, not at all like other vapour harmony methods, pore water pressure estimations are specifically acquired from example mounted tensiometers as opposed to through a circuitous connection with relative dampness, in this way escaping errors because of temperature affectability (Blatz & Graham, 2000; Tang & Cui, 2005). An alternate key preference of the air flow strategy over accepted vapour harmony methods lies in the likelihood of controlling pore water pressure over a constant go as opposed to in discrete steps. Notwithstanding, the system by Cunningham (2000) could just be utilized for monotonic drying or for keeping pore water pressure consistent throughout tests when pore water pressure had a tendency to drop throughout stacking yet couldn't be utilized to force a wetting way to the specimen. A further impediment was given by the absence of water substance estimations.

Jotisankasa (2005) and Jotisankasa et al. (2007) proposed an enhanced suction control system dependent upon comparable standards. In their system, relative dampness was measured at the bay and outlet of the air flow line at the base of the example. Any distinction between these two estimations was credited to moisture trade with the specimen, accordingly empowering computation of water substance throughout tests. Jotisankasa (2005) additionally stretched out the system to permit wetting of the example. Initially by wetting the dirt by sodden air flow yet this demonstrated incapable, so wetting was performed by physically infusing a known volume of water into the air dissemination line. After each one wetting step, pore water pressure and strains were observed until stable qualities were measured. The method furnished an approach to force discrete progressions of pore water pressure however completed not permit the same congruity of control as throughout drying. Because of the coarseness of wetting steps, the specimen base encountered expands in pore water pressure as extensive as 50kpa promptly after infusion, emulated by a reduction again throughout leveling. This is not attractive when monotonic wetting ways must be emulated and water driven hysteresis must be escaped. Moreover, water substance progressions were by implication computed by utilizing a thermodynamic balance relationship between relative moistness (measured at the channel and outlet of the air flow line at the base of the specimen) and the mass of water vapour conveyed in the flowing air. This relationship was dependent upon the suspicions of isothermal research center conditions and unlucky deficiency of head misfortunes throughout air flow. However, both these assumptions will only be partly met during real tests and are likely to introduce errors in water content measurements. A further potential source of error was due to the formation of water droplets inside the air circulation line caused by condensation. This moisture could not be accounted for and introduced a degree of inaccuracy in the measurement of water content.

DRYING SYSTEM

The system depicted in this paper was created for testing unsaturated soil examines inside a twofold divider triaxial unit (DWTC). Be that as it may, it could be effortlessly adjusts to different instruments, for example, oedometers and shear boxes. The DWTC was made by Wykeham Farrance Ltd. A change was presented by penetrating a hole through the base platform where the tensiometer could be embedded to be in contact with the specimen. Two coarse permeable plates were put at the top and base limits of the specimen, with the lowest part plate having an opening bored through to permit insertion of the tensiometer. An o-ring fixing around the tensiometer form anticipated water evaporation from the specimen.

Controlled drying was accomplished through course of air in contact with the specimen by utilizing the set-up. Air was pumped in a shut circle that incorporated a moisture trap comprising of a plastic container holding silica gel. The moisture trap upheld a dry environment inside the air flow line and anticipated buildup in the tubing. Air dissemination inside the shut circle was forced by an in-line stomach pump (model Boxer 3114 with a free flow rate cited by maker of 28 l/min), which could operate persistently for long times of time. The flow rate hinged on upon the voltage supplied to the pump, which ran between 6v to 12v. In this research the pump was constantly operated at 12v comparing to the greatest flow rate conceivable.

The water lost from the example was accepted equivalent to the water picked up by the silica gel inside the moisture trap, which was recorded by having the container loaded with silica gel resting on an advanced balance (model Oertling with a precision of ±0.1g). Readings from the balance were logged in by the data obtaining system through a RS 232 interface.

Because of the firmness of the tubes associated with the moisture trap, any relative development between the tubes and the balance is prone to present mistaken mass variety. Such failures were minimized by altering the tubes to the seat and by physically securing the zone around the supplies. An elective outline was later contrived for the moisture trap, where silica gel was set on the balance presented to the climate inside an air-tight box, which was thus joined in accordance with the air flow circle. Hence, no tubing was resting on the balance and potential blunders in the estimation of mass progressions were accordingly succeed. Because of time restrictions, this enhanced configuration was just tried in the wetting set-up.

Pore water pressure was measured at the base of the example by method of a high suction tensiometer in contact with the dirt through an opening in the unit platform. The tensiometer is fit for measuring negative pore water pressures down to -2mpa (Lourenço et al., 2006; 2008), then again it ought to be noted that this utmost may not dependably be attained and cavitation can happen at more level pore water pressures.

Drying was controlled through an input computer system dependent upon constant pore water pressure perusing from the tensiometer. The control software TRIAX (Toll, 1999) was utilized to secure data through a MSL data scan unit and to control devices (i.e. to switch on or off the pump and control cell pressure through stepper engine driven cylinders) by means of a PCI 836-A computerized input/output card. Given that the PCI card gives a yield indicator of 5v, a converter had additionally to be utilized for intensifying voltage to 12v with a specific end goal to control the air pump.

The following two sections investigate additional aspects related to the performance of the desiccant and to the excess air pressures generated during operation of the pump.

Silica gel moisture trap : Silica gel is a synthetic amorphous material with spherical particles of colloidal silica (SiO_2). It is composed of a network of interconnected microscopic pores with different sizes. Average pore sizes range between 1.1nm to 6.8nm (Pesaran & Mills, 1987). This structure gives a high internal specific surface area (500-900m2/g), which is responsible for its high moisture adsorption capacity.

A series of preliminary tests were performed to explore the moisture adsorption capacity of silica gel. Three different amounts of initially dry silica gel equal to 394g, 788g and 1200g were placed on a digital balance while exposed to the laboratory environment. As the silica gel adsorbed moisture from the atmosphere, mass readings from the balance increased with decreasing rate until achieving equilibrium at a relative humidity of approximately 55%, corresponding to typical laboratory conditions.

Based on the results of the above tests, it was considered that a mass of dry silica gel of approximately 800g would not require frequent replacement during tests. Note that higher relative humidity will exist within the air circulation line compared to laboratory conditions because of the relatively high pore water pressures inside soil samples during testing.

Excess air pressure : If air is forced to circulate through the soil sample, a gradient of excess pore air pressures will develop between the two extremities of the specimen. Even if the cell pressure is adjusted to control the applied net stress, a pressure gradient would still result in a heterogeneous net stress distribution across the sample. The magnitude of this gradient will depend on the soil air permeability (which in turn depends on the intrinsic permeability and degree of saturation of the soil) and on the geometry and diameter of the different sections of tubing forming the air circulation loop. The generation of excess pore air pressures and relative gradient can be reduced by introducing short-cut flow routes into the air loop, such as an external bypass to the sample or geotextile drains around the specimen sides.

The geotextile drain was a woven polypropylene fabric, which completely wrapped the sample along the lateral surface, top and bottom extremities.

Flow through the external bypass enhanced evaporation from the top and bottom surfaces as air moves across the coarse porous stones (Cunningham *et al.*, 2003) while flow through the geotextile drains provides further drying potential along the sides of the sample.

A testing program was carried out in order to define the best way of minimizing air pressure gradients in the sample. Tests were conducted with a dummy sample made of four dry porous sandstone discs with a saturated water permeability of about 10-7m/s. An initial confining pressure of 130kPa was applied to the dummy sample while air was circulated through: (1) sample only, (2) sample with external bypass, (3) sample with external bypass and geotextile.

Results from controlled soil drying : A sample of sandy clay soil (Plastic Limit 17%; Liquid Limit 33%) with dimensions 105x115.5mm was compacted dynamically at a water content of 18.0% resulting in a void ratio of 0.51 and degree of saturation of 92.2%. This water content corresponds to a pore water pressure of approximately -300kPa. A specimen with height 30mm and diameter 105mm was then trimmed and mounted inside the DWTC.

A preliminary test was carried out to explore the capabilities of the drying system by manually switching the pump on/off. The target pore water pressure was progressively decreased in five consecutive steps corresponding to values of -200kPa, -300kPa, -500kPa, -800kPa and -1200kPa. For each step, pore water pressure was manually controlled within a tolerance of ±10kPa by switching the pump off if pore water pressure fell below the lower tolerance, and turning it back on if pore water pressure rose above the upper tolerance.

Given the unexpected cavitation of the tensiometer observed in the previous test, a second controlled drying was performed on a similar sample to verify the relationship between water pressure and mass variations. The results indicate that an initial step change of mass is recorded while pore water pressure is rapidly lowered to the initial target. Subsequently, as equalization takes place, mass readings increase at a faster rate during the initial stage, but become approximately constant when pore water pressure starts to equilibrate throughout the sample.

WETTING SYSTEM

In the wake of improving an automated system for controlled drying of soil specimens, the ensuing stage was to select a suitable wetting methodology. Two elective choices were tried in this work comparing to wetting by water vapour or liquid water.

Wetting by water vapour : A first endeavor to accomplish controlled wetting was made by coursing vapour-saturated air in contact with the dirt specimen (rather than dry air as in past tests). The moisture trap of the drying system was swapped by a wellspring of wet air comprising of a „bubbling box‟ incompletely loaded with refined water through which air was rising as it flowed inside the air flow circle. With a specific end goal to guarantee that the air relative mugginess was equivalent to 100%, a ultrasonic small fogger (supplied by Maplin) was submerged to generate fog inside the case.

An example of the same sandy mud utilized within past tests was compacted at a generally low water substance of 13% and mounted inside the twofold walled triaxial unit under a keeping pressure of 200kpa. After pore water pressure stabilized at a consistent quality, wet air from the foaming box was compelled to flow through the specimen for a time of 2h50m. This was rehashed three times with air flowing through and through throughout the first two tests and base to top throughout the third test. The air pressure was screened by a transducer in the tubing associated with the highest point of the example.

Wettability of the dirt relies on upon the capability of water to be exchanged from the coursing air to the example. For this to happen, the relative dampness of the circling air must be more excellent than the relative stickiness in balance with the pore water pressure inside the example. Because of the generally high pore water pressure inside the specimen, the circling air must have a relative moistness well in abundance of 99% to empower wetting of the dirt.

Wetting by liquid water : The troubles in expanding pore water pressure by dissemination of muggy air expedited an amended outline of the suction control system , where wetting was currently attained by immediate infusion of liquid water. A water volume check was associated with the air flow circle through a solenoid valve controlled by the TRIAX software. The volume check was forever pressurised at 200kpa with the goal that little measures of water could be let inside the air dissemination circle by quickly opening the solenoid valve. Also, the volume measure was positioned above the triaxial cell with the goal that gravity could encourage dribbling of water towards the specimen.

Throughout wetting, the solenoid valve was opened at normal interims to infuse water inside the shut circle tubing while air was coursed to redistribute moisture on the example surface and to accelerate water allow by the dirt. Moreover, a moisture trap maintained a strategic distance from buildup inside the tubing and avoided pounding of water inside the system. The water mass infused by the volume measure and that adsorbed by the silica gel inside the moisture trap were both screened so changes of the dirt water substance could be figured from their distinction. At long last, pore water pressure was measured by a tensiometer spotted at the bottom surface of the example.

The configuration of the moisture trap was additionally enhanced as for the drying set-up long ago portrayed. The silica gel was presently specifically presented to the air inside an open tray set on a computerized balance, which was encased in an Ip67 standard waterproof box with measurements 0.38m x 0.29m x 0.25m (produced by Sarel). This case was remotely associated with the air dissemination circle so no tubing or link was joined to the silica gel, therefore escaping potential failures in the mass estimation (Toker et al., 2004). The space inside the container was deliberately decreased to the base conceivable so as to accelerate the adsorption of water by the silica gel and decrease equilibration time.

Wetting and drying cycles : The first wetting test was carried out on a sample of the same sandy clay soil used in previous tests compacted at w=17% with a void ratio of 0.53. The primary objective was to evaluate the accuracy of wetting paths but the test included both drying and wetting so that the entire suction control system could be checked at once.

After setting the sample in the DWTC, an isotropic pressure of 335kPa was applied and the pore water pressure was decreased to -400kPa. Eight wetting-drying cycles between -400kPa and -200kPa were applied to the sample using the water injection system previously described. Pore water pressure was measured by a tensiometer at the base of the sample while the mass of water adsorbed by the silica gel and the mass of water injected by the pressurized volume gauge were simultaneously recorded. During wetting, air was simultaneously circulated to redistribute moisture on the sample surface and to help water intake from the soil. Initially, the sample was wetted at a rate of 1 injection / 6 min (where one injection means one open-close signal sent to the solenoid valve); however a decrease of pore water pressure to -1100kPa was observed instead of the expected increase, due to predominance of drying due to the circulating air. The wetting rate was therefore increased to 1 injection / 3 min in subsequent cycles.

CONCLUSIONS

New improvements of a tensiometer based suction control system for research center testing on unsaturated soil were exhibited, amplifying past work by Cunningham (2000) and Jotisankasa (2005). The execution of the system was demonstrated by forcing drying-wetting ways on compacted soil examines inside a twofold walled triaxial unit. Specimens were dried by flowing air through a desiccant (silica gel) inside a shut circle system or wetted by specifically infusing water. Changes in the specimen water substance were measured as the contrast between the water masses infused and adsorbed by the silica gel, separately. The system furnished automated control of pore water pressure and utilized a novel methodology to get persistent estimations of progressions in the example water content. Estimations of water substance were dependent upon persistent weighing of the desiccant and an immediate record of the water volume infused through a computer-controlled solenoid valve joined with a pressurized volume check. The proposed suction control system maintains a strategic distance from the necessity to lift air pressures, as needed by the pivot interpretation strategy, and consequently better repeats regular wetting and drying techniques. The system was ready to dry and wet to an obliged pore water pressure; however wetting was not as effortlessly controlled as drying and, throughout wetting, tensiometer estimations had a tendency to overshoot essentially the target pressure. The wetting system still needs further change and, specifically, acceptance of the exactness of the water content estimation. Indeed by taking all vital precautionary measures for fixing the air course circle, there was still dissemination of moisture from the outside environment towards the desiccant. This brought about a long haul float of the adsorption water mass comparing to a pretty nearly consistent rate of 0.07g/day. This might not so much represent an issue, furnished that the float rate remained steady and could accordingly be made into note of in the estimation system through subtraction from the measured qualities. The system was utilized with a twofold divider triaxial set-up, yet could additionally be acclimates for utilization with different instruments, for example, for instance, oedometers or shear boxes. The system might be utilized to perform tests emulating drying or wetting ways and to run either suction controlled or water substance controlled tests.

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