Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Evaluation Of Water Infiltration Characteristics In Clayey Soils With Sand Drain

Prasanna Venkatesh[1], Naga Surya Vamsi[2] and Jeevan Joseph[3]

[1] National Institute of Technology Tiruchirappalli, Trichy – 620015, India
[2] National Institute of Technology Tiruchirappalli, Trichy – 620015, India
[3] National Institute of Technology Tiruchirappalli, Trichy – 620015, India
jeevan@nitt.edu

Abstract: Water scarcity has been a major issue worldwide owing to various reasons such as climate change, global warming, increasing population, etc. Moreover, it's a known fact that the majority of the rainfall is wasted as runoff due to the presence of impervious strata such as pavements, impermeable soils, etc. Thus, proper rainwater management becomes the need of the hour to overcome this crisis. The present experimental studies detail the improvement in infiltration rate and volumetric water content of two clayey soil having distinct water retention properties by installing a sand drain. The variation in infiltration rate with time followed a three staged pattern with a high initial infiltration rate due to cracks in the sample until the pre-healing time after which the cracks got sealed. Thereafter, the infiltration rate followed a declining trend until an equilibrium value was reached. Provision of sand drain resulted in an improvement of initial infiltration rate by 5 times and 2 times which subsequently subsided to an equilibrium value of 1.5 times and 1.3 times at 72 hours in soils C1 and C2 respectively. Moreover, the volumetric water content of the soil sample resulted in an improvement of up to 1.4 times and 1.5 times in case of soil C1 and C2 respectively.

Keywords: Clay, soil water retention properties, sand drain, infiltration rate, volumetric water content.

1 Introduction

Drought has been identified to be one of the major natural hazard which has significant agricultural, ecological, and socioeconomic impacts [1]. The arid and semiarid regions are generally more susceptible for drought, the major reason being insufficient rainfall, extreme high temperature and less relative humidity [2,3]. Also, the available water resources are highly stressed lately due to various factors such as increase in population, industrial growth, socioeconomic factors, and climatic conditions (Temperature, Precipitation) [4]. The water stored in the soil is the key source for plants in arid and semi-arid region due to the limited precipitation and deeper ground water depths [5].

Among various factors, stiffening of soil layer during drying known as soil crusting is a common phenomenon in arid and semi-arid regions which affects the water infiltration rate into soil [6,7]. Previous studies have inferred that the soil crusting can reduce the infiltration rate considerably, (0.1mm thickness of crusted soil reduced the infiltration rate by 10 times) [8]. Moreover the infiltration rate decreased twice when the thickness of crusted soil was increased from 0.1mm to 0.2mm [9].

Thus owing to poor infiltration rate in surface crust, provision of sand column can bypass this layer, enabling water to infiltrate into the soil beneath. Various field studies reported that sand columns resulted in one or more of the following benefits such as the improvement of infiltration rate, rainwater storage against runoff, and soil water content etc [10,11,12]. In accordance with the field studies, a similar Laboratory study also proved that the sand drains increased the rainfall storage up to 73% [13]. An experimental and numerical study (MODFLOW [14]) on the efficiency of sand drain on groundwater recharge placed in the base of a dam were carried out by considering the effect of parameters such as head difference, soil layer thickness, and sand drains density [15,16]. However, In most of the studies employing sand drains, very less attention was given on its effectiveness and suitability based on the properties of the soil.

Thus, in this paper the effect of sand drains and the infiltration mechanism on two clayey soils with different soil water retention properties were experimentally studied.

2 Materials And Methodology

The Soil samples for the study were collected from Kumbakonam (C1) and Thirukkuvallai (C2) (Tamil Nadu, India). The soils C1 and C2 were classified as CL and CH based on Unified Soil Classification system. The basic soil properties of the clay soils and the sand used for sand drain are as listed in the Table 1 and Table 2 respectively. The specific surface area by EGME Method [17] and the Cation Exchange Capacity, CEC (ASTM D7503-18) [18] of the soil were also measured and reported herein. The Soil water Characteristics Curve were then plotted using the experimental data points obtained by contact filter paper technique (ASTM D5298) [19] fitted with the Van Genuchten Model (1980) using RETC software [20] as shown in Fig 1.

Table 1. Properties of clay soil.

Sl No	Soil Property	Clay Soil 1 (C1)	Clay Soil 2 (C2)
1	Specific gravity	2.68	2.66
2	Liquid limit	44%	51%
3	Plastic limit	21%	19%
4	Shrinkage limit	11%	10%
5	Soil classification (USCS)	CL	CH
6	Clay percent	36	47
7	Free swell index	33%	50%
8	Specific Surface Area (m^2/g)	158	188
9	Cation Exchange Capacity CEC (mequiv/100g)	31.6	63.5

Table 2. Properties of Sand.

Sl No	Soil Property	Sand (S)
1	Specific gravity (G)	2.65
2	D10 (mm)	0.55
3	D30 (mm)	0.68
4	D60 (mm)	0.87
5	Cu	1.58
6	Cc	0.96
7	$\gamma_{d\ min}$ (g/cc)	1.53
8	$\gamma_{d\ max}$ (g/cc)	1.71
9	e_{min}	0.53
10	e_{max}	0.71
11	Soil Classification (USCS)	SP

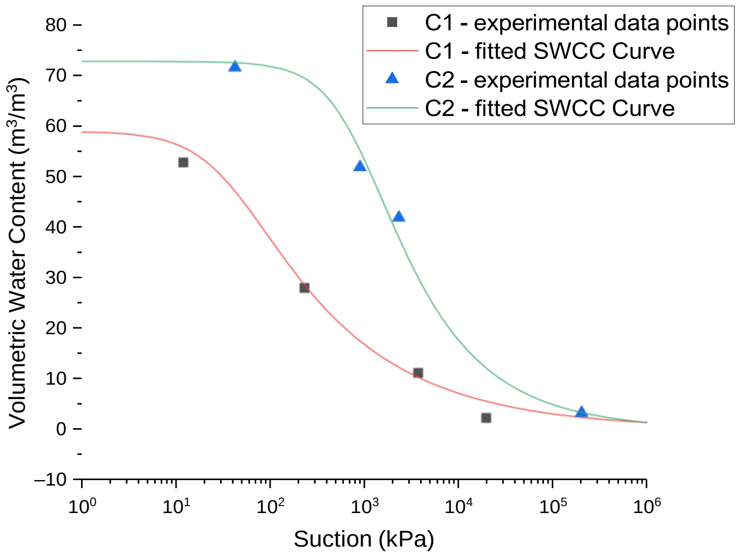

Fig. 1. Soil Water Characteristic Curve

Two different methodologies (M1 and M2) were followed in sample preparation for infiltration test in clay soils alone (M1) and in clay soils with sand drain (M2). The infiltration tests were conducted on an acrylic cylindrical mould of 10cm diameter and 15cm height connected with a top and bottom plate as shown in Fig 2. The top plate is provided with a water inlet valve and an air vent valve. Initially in M1 case, in order to make uniform soil samples, the dry soil passing through 425 micron sieves were mixed with a water content equal to Liquid Limit and were filled inside the mould with regular tapings to avoid entrapped pore air. The filled soil samples were then allowed to dry before the start of the experiment. In M2 case, a PVC pipe was installed at the center of the soil before filling of clay soil which was later removed after pouring sand. The sand was poured from a height of 1 cm to maintain a relative density of 30%. The length of the sand drain was adopted as 0.75 times the height of the clay soil (H_s) and the diameter of the sand column was chosen as 1cm. The initial water content and the dimensions of the dry sample were noted in each case prior to testing as shown in Table 3. The circumference of the dry soil was covered with cling film and the additional space between the soil and the setup were filled with Paraffin Wax in order to avoid water infiltration through the sides. A filter paper and the porous stone was then kept over the sample. The Pressure Volume Control device (GDS Instruments), that could facilitate controlled release of water at the desired pressure range (5kPa in the current study) has been utilized for the infiltration test. Further PVC device allowed precise measurement of the volume of water infiltrated into the soil.

Table 3. Dimensions of clay soil used for testing

Sl No	Soil	Diameter of soil D_s (cm)	Height of soil H_s (cm)
1	C1 without drain	9	10
2	C1 with drain	8.9	10.6
3	C2 without drain	8.2	11.9
4	C2 with drain	8.1	10.9

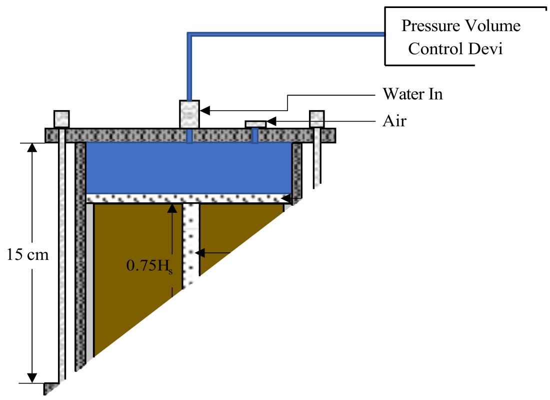

Fig. 2. 1D Free Swell Infiltration Experimental setup

3 Results and Discussion

The infiltration tests were continued for 72 hours after which the change in infiltration rate became negligible. The change in infiltration rate with time for all the cases are plotted as shown in Fig 3.

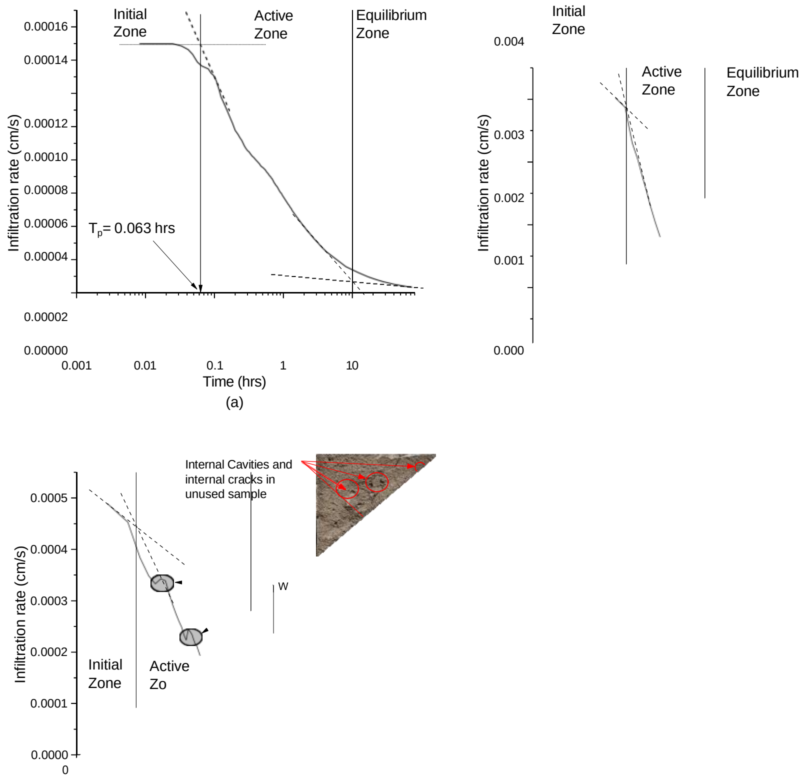

Fig. 3. Infiltration rate vs time for a) C1 without sand drain b) C1 with sand drain c) C2 without sand drain d) C2 with sand drain

Further, it is observed that the infiltration rate of the soil sample followed a three staged pattern which was in accordance with the previous study conducted on infiltration rate in cracked soil (Cheng et.al, 2021). The prevailing cracks and the high adsorption potential of dry clay soil in the initial zone results in a higher constant infiltration rate until pre-healing time, which is the time taken for the closure of cracks in soil. Beyond the prehealing time, as the soil starts to swell resulting in closure of cracks and filling of macropores, the infiltration rate reduces over time in the active zone and finally reaching an equilibrium value.

The easier access of water into the clay soil due to the provision of sand drains resulted in early swelling and closure of cracks, thus the pre-healing time decreased from 0.063hr to 0.0043hr in case of soil C1 and from 0.0073hr to 0.0022hr in case of soil C2 when provided with sand drain as shown in Fig 3. The fluctuations in infiltration rate observed in the active zone can be related to the water entry into the internal cavities and the internal cracks present in the soil as shown in Fig 3 c.

Provision of sand drain resulted in an improvement of initial infiltration rate by 5 times and 2 times whereas the final Infiltration rate at the equilibrium zone was increased by 1.5 times and 1.3 times when provided with sand drains in case of soil C1 and C2 respectively.

The volumetric water content of the soil was calculated by precisely measuring the volume of water entered into the soil by using Pressure Volume Control device and thus the variation of volumetric water content with time is plotted for both soil C1 andC2 with and without sand drain as shown in Fig 4.

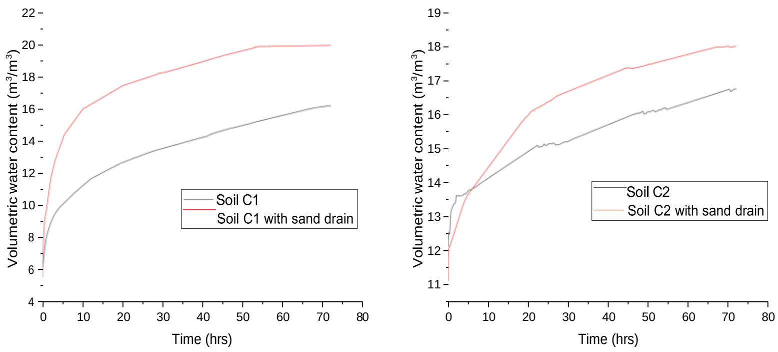

Fig. 4. Variation of volumetric water content with time

The increase in volumetric water content of the soil samples after 72 hrs of infiltration is 2.75 times, 3.54 times in case of soil C1 without and with sand drain respectively whereas 1.38 times, 1.62 times in case of soil C2 without and with sand drain respectively. Also it is observed that the provision of sand drain resulted in 40% and 50% net increase in volumetric water content in case of soil C1 and C2 respectively.

Effectiveness of Sand Drain

The volume replacement of clay with sand was as minimum as 0.95% and 1.14%, which resulted in an increase of 50% and 31% of final infiltration rate in case of soil C1 and C2 respectively. Moreover, there is an increase in 40% and 50% of volumetric water content for soil C1 and C2 respectively. Thus it is evident that for increasing the infiltration rate and volumetric water content of the fine grained soil, a very minimal volume replacement of sand drain is adequate. This indicates the cost effectiveness of employing sand drains for effective water recharge into the fine grained soil.

Even though the previous field studies [10,11,12] didn’t comment on the suitability of sand drains based on the soil specific parameters, however the implementation of employing sand column in field and the result of these studies indicate the practicability of using sand drains for efficient recharge of water into fine grained soil in field.

4 Conclusion

1. The infiltration rate of the soil sample followed a three staged pattern namely Initial Zone, Active Zone and Equilibrium Zone, which was in accordance with the previous study conducted on infiltration rate in cracked soil.

2. The final Infiltration rate at the equilibrium zone increased by 50% and 31% times when provided with sand drains in case of soil C1 and C2 respectively.
3. The provision of sand drain resulted in 40% and 50% net increase in volumetric water content when provided with sand drain in case of soil C1 and C2 respectively.
4. Even though the improvement in the infiltration rate when provided with sand drain was higher in case of soil C1, the net improvement in volumetric water content was higher in case of soil C2. Thus the soil water distribution is improved better in case of soil with higher water retention capacity (C2) when provided with sand drain. Hence the provision of sand drain are highly efficient when used for soil with higher water retention capacity.
5. The volume replacement of clay with sand was as minimum as 0.95% and 1.14%, which resulted in an increase of 50% and 31% of final infiltration rate and an increase in 40% and 50% of volumetric water content in case of soil C1 and C2 respectively.

Acknowledgements
We gratefully acknowledge that this work was supported and funded by the Science and Engineering Research Board (SERB), Government of India (Sanction No: ECR/2018/002632).

References

1. Dabrowa, A., Neal, J.C. and Bates, P.D.: Floods and Storms Practical Exercises. Hydro-Meteorological Hazards, Risks and Disasters, 213-229 (2015).
2. Surendran, U., Anagha, B., Raja, P., Kumar, V., Rajan, K. and Jayakumar, M.: Analysis of drought from humid, semi-arid and arid regions of India using DrinC model with different drought indices. Water Resources Management 33(4), 1521-1540. (2019).
3. Bullock, J.A., Haddow, G.D. and Coppola, D.P.: Homeland Security: The Essentials. 2nd edn. Elsevier BV, USA (2013).
4. Tripathi, D.K., Singh, V.P., Chauhan, D.K., Sharma, S., Prasad, S.M., Dubey, N.K. and Ramawat, N.: Plant Life Under Changing Environment: Responses and Management. 1st edn. Academic Press, London (2020).
5. Geroy, I.J., Gribb, M.M., Marshall, H.P., Chandler, D.G., Benner, S.G. and McNamara, J.P.: Aspect influences on soil water retention and storage. Hydrological Processes 25(25), 3836-3842 (2011).
6. Valentin, C. and Bresson, L.M.: Soil crusting. Methods for assessment of soil degradation, 89-107 (1997).
7. Moncada, M.P., Gabriels, D., Lobo, D., De Beuf, K., Figueroa, R. and Cornelis, W.M.: A comparison of methods to assess susceptibility to soil sealing. Geoderma 226, 397-404 (2014).
8. McIntyre, D.S.: Soil splash and the formation of surface crusts by raindrop impact. Soil Science 85(5), 261-266 (1958).
9. Wakindiki, I.I.C. and Ben-Hur, M.: Soil mineralogy and texture effects on crust micromorphology, infiltration, and erosion. Soil Science Society of America Journal 66(3), 897-905 (2002).
10. Abu-Awwad, A.M. and Shatanawi, M.R.: Water harvesting and infiltration in arid areas affected by surface crust: examples from Jordan. Journal of Arid Environments 37(3), 443-452 (1997).
11. Abu-Awwad, A.M.: Effects of sand column, furrow and supplemental irrigation on agricultural production in an arid environment. Irrigation Science 18(4), 191-197 (1999).
12. Abu-Zreig, M., Attom, M. and Hamasha, N.: Rainfall harvesting using sand ditches in Jordan. Agricultural Water Management 46(2), 183-192 (2000).
13. Attom, M.F., Khan, Z. and Vandanapu, R.: Efficacy of sand columns to increase the subsoil moisture content of clay. SN Applied Sciences 2(5), 1-6 (2020).
14. McDonald, Michael, G., and Arlen, W.H.: A modular three-dimensional finite-difference ground-water flow model. US Geological Survey, (1988).
15. Akhmad, A.: Performance analysis of sand columns in recharge reservoir. International journal of Engineering and Technology 4(10), 577-581 (2014).
16. Azis, A., Badaruddin, S., Faisal, Z., Iqbal, M.T. and Hasanuddin, H.A.: Numerical model on the application of sand columns in recharge reservoir. Groundwater for sustainable development 8, 368-372 (2019).
17. Cerato, A.B., and Alan J.L.: Determination of surface area of fine-grained soils by the ethylene glycol monoethyl ether (EGME) method. Geotechnical Testing Journal 25, no. 3, 315-321 (2002).
18. ASTM D7503-18: Standard Test Method for Measuring the Exchange Complex and Cation Exchange Capacity of Inorganic Fine-Grained Soils. ASTM International, West Conshohocken, Pennsylvania (2018).
19. ASTM D5298-10: Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper, ASTM International, West Conshohocken, Pennsylvania (2016).
20. Leij, F.J., Van Genuchten, M.T., Yates, S.R., Russell, W.B. and Kaveh, F.: RETC: A com-puter program for analyzing soil water retention and hydraulic conductivity data. Indirect methods for estimating the hydraulic properties of unsaturated soils. University of Califor- nia, Riverside, 263-272 (1992).