6. Analysis of the Effect of Rainfall Intensity on Capillary Shock Time and Capillary Shock Height in Fine-Grain Soil Layers

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Submission date: 06-Apr-2023 10:48AM (UTC+0700)
Submission ID: 2057227679
File name: ck_Time_and_Capillary_Shock_Height_in_Fine-Grain_Soil_Layers.pdf (247.57K)
Word count: 3963
Character count: 20311

International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V71I2P211

Volume 71 Issue 2, 89-97, February 2023
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Original Article

Analysis of the Effect of Rainfall Intensity on Capillary Shock Time and Capillary Shock Height in Fine-Grain Soil Layers

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Received: 03 October 2022 Revised: 31 January 2023 Accepted: 07 February 2023 Published: 25 February 2023

***Abstract** - After first successfully validating the capillary shock test model that the research team specifically designed, the research continued by using media of fine-grained soil types. This test was carried out with the aim of analyzing the extent of the influence of the rainfall intensity parameter on the capillary shock parameter. In addition, the use of fine-grained soil was chosen as a simulation medium to observe the capillary shock process because we wanted to know the relationship between soil particle size and the capillary shock parameters that occurred. There are 3 variations of rainfall intensity levels, each with a return period of 5 years, 15 years, and 25 years (I_5, I_{15}, and I_{25}). The types of fine-grained soil used as media are sandy, silty clay, silty sandy clay, and sandy, clayey silt. From a series of laboratory test results, it was found that; (1) The intensity of rainfall has a very significant influence on the capillary shock parameters, both on the capillary shock time and on the capillary shock height. The higher the intensity of rainfall at the beginning of the rainy season, the shorter the capillary shock time, and the lower the capillary shock height that occurs. (2) The effect of fine-grained soil particle size on capillary shock parameters is also very significant, both on capillary shock time and on capillary shock height. The finer the soil particles, the longer the capillary shock time and the higher the capillary shock height.*

***Keywords** - Capillary shock, Capillary shock height, Capillary shock time, Fine grained soil, Rainfall intensity.*

1. Introduction

The research team first observed the capillary shock phenomenon from 2012 to 2014 when observing the impact of groundwater release from farmers' irrigation wells in Takalar Regency, South Sulawesi (Indonesia). In observations made at that time, a phenomenon was recorded where there was a very significant degradation of the groundwater level at the beginning of the rainy season. Furthermore, the authors analyzed the factors causing this phenomenon, namely that during the dry season, the soil pores enlarge on the surface (pendular zone and funicular zone) so that the high capillary pressure in the capillary zone decreases. Furthermore, at the beginning of the rainy season, there is a reduction in soil pore cavities on the surface, which results in an increase in capillary pressure, which causes groundwater in the saturated zone to be sucked in a vertical direction so that the phreatic groundwater level decreases significantly. This kind of phenomenon, the authors, is called “capillary shock” [1].

Based on the analysis results, the research team designed further research using a special model tool, which was intended to perform a simulation to observe the process of the capillary shock phenomenon. In this study, 5 types of coarse-grained soils with varying intensity levels (5 return periods) were used. From the simulation research that has been carried out, it has proven the accuracy of the modelling tools used, and from these tools can also be identified capillary shock parameters, namely "capillary shock time" and "capillary shock height" [2]. After the team's design of the capillary shock model had proven its accuracy, this time, the study was conducted to observe the capillary shock phenomenon that occurs in fine-grained soil layers. This is very important because such a soil layer will experience a change in the void ratio at the beginning of the rainy season, which is greater than that which occurs in the granular soil layer.

Changes in capillary pressure in the soil layer will affect the fluid flow pattern in the soil layer. Fully understanding the mechanisms of immiscible displacement at the pore scale dominated by capillary forces, particularly local instability and their effect on flow patterns, is critical for a wide range of industrial and environmental applications such as increased oil recovery, CO2 geo-sequestration and remediation of contaminated aquifers. It is well known that the immiscible displacement is very sensitive to the fluid properties and pore structure, especially the porous media's wetting properties, which affects the micro scale's local interface instability and the displacement pattern at the macro scale [4].

The permeability properties of the soil layer strongly influence fluid flow in the soil layer with very small pores. In low-permeability shale reservoirs, this flow is driven by capillary pressure, which is very important because the dominance of the nanoscale pores will increase the capillary pressure and weaken the viscous hydrodynamic forces. The surface roughness adds extra resistance during the capillary rise process, which counts as an equivalent porous medium layer. The capillary model was extended to a porous medium using the capillary bundle concept [5].

2. Materials and Methods

2.1. Materials

By the title of this article, the soil media used in model testing are 3 types of fine-grained soil, namely ; (1) sandy silty clay, (2) silty sandy clay, and (3) sandy clayey silt. Likewise, to observe the effect of rainfall intensity, 3 levels of return periods are applied, namely: $I_5 = 230.28$ liters/hour, $I_{15} = 375.94$ liters/hour, and $I_{25} = 496.48$ liters/hour.

The modeling of the capillary shock simulation tool was carried out to simplify and maximize further research on the phenomenon of capillary shock. All research tools and materials are prepared in such a way as to support perfection and minimize errors when research is carried out. The image of the capillary shock model used can be seen in Figure 1 below :

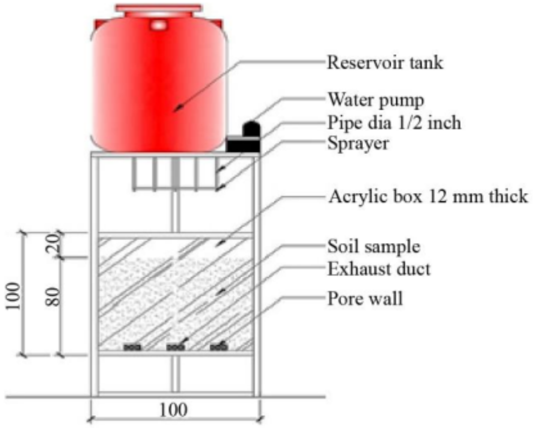

Fig. 1 Capillary Shock Test Model Tool

In Figure 1 above, it can be seen that there are various parts that have their respective functions and have been designed to facilitate testing during the running test and simulation process—the water reservoir functions as a reservoir for water according to the intensity used. The water pump functions as a water booster during rain simulations to ensure that the rain remains constant. The water pipe serves as a channel for water from the reservoir to the sprayer, a transparent tub as a medium for soil samples, on the other hand, as a groundwater level control tank. Drain channel as a cleaning channel, and pore stones as a medium for water seepage from the control tank to the soil sample media tank.

2.2. Methods

This research was carried out using an experimental research model method, which was intended to observe carefully the process of the capillary shock phenomenon that occurred. The procedure for carrying out tests carried out sequentially consists of; the process of preparing tools and media samples, checking soil characteristics as media samples, calibrating capillary shock models, and running tests consist of several processes, namely, preparation, an inspection of soil media, calibration, and running test. Test preparation is very important because it includes things that must be done before the test is carried out so that observations can take place properly, such as cleaning tools, checking materials, checking all instrument elements, and preparing personnel and stationery for observations.

After all the preparations were complete, it continued by examining the characteristics of the soil media. In this case, the soil media must be ensured to be dry and loose before testing. In addition, the tool calibration process also needs to be carried out to match the amount of simulated water equal to the intensity of the rainfall used. Calibration of the tool is done by filling the water reservoir according to the intensity with a measuring cup with a capacity of two liters until it reaches the specified intensity. Then the sprayer is set to the spray opening. The rain simulation is carried out for one hour with the pump condition as a water booster to keep the water spray constant.

After all these processes are complete, the model testing can be carried out (running test). At first, the simulation tank was filled with soil samples, and then the soil samples were compacted using a vibrator. The compaction method was carried out in each layer 20 cm thick, carried out 5 times to produce media with a total thickness of 80 cm (assuming that the density of the sample was the same as the density of the soil in the field). The groundwater level control tank, which is assumed to be a water well or hole in the field, is filled with 50 cm of water allowed to seep into the soil media through the pore stones. If the water runs out, add water at 15cm intervals until the height of the puddle in the media has the same height. This is intended to match the groundwater conditions in the test media with the groundwater conditions in the soil layer in the field. The top of the capillary shock simulation device is closed using a transparent plastic curtain to prevent water loss during the test. The rain simulation process and capillary shock measurements are ready to be carried out. Then the running test process begins, and immediately after that, the sprayer and the water pump machine are run simultaneously with the stopwatch. Observations of changes in groundwater level in the saturated zone were observed over time. Observations will be stopped when water spray from the sprayer with the intensity of the duration has been completed and the groundwater level in the soil media has reached its maximum elevation.

3. Results and Discussions

3.1. Results

From a series of observations of the two capillary shock parameters that occurred in 3 types of fine-grained soil layers and also with 3 variations of rainfall intensity, several images were produced, which are shown in the following graph :

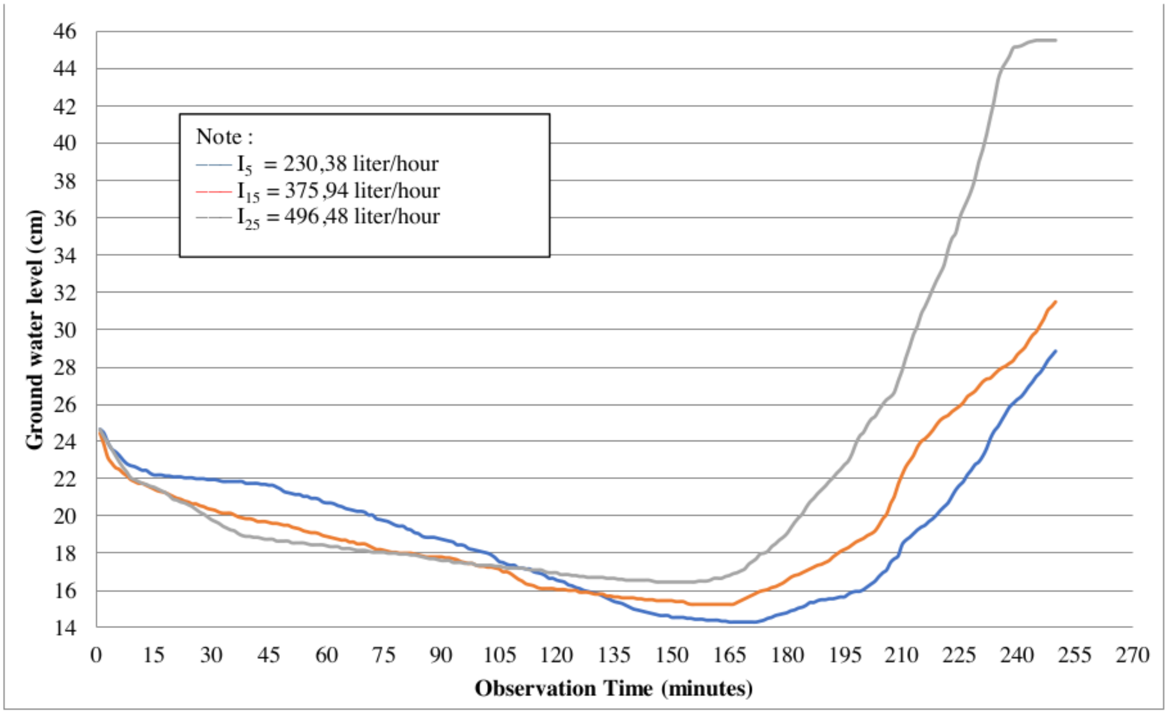

Fig. 2 Groundwater Level Fluctuation on Sandy Silty Clay with Rainfall Intensity Variations I_5, I_{15}, and I_{25}

From Figure 2 above, it can be read the value of capillary shock time and capillary shock height on sandy silty clay soil types as follows :

- At I_5; capillary shock time = 172 minutes.
  capillary shock height = 10,70 cm.
- At I_{15}; capillary shock time = 166 minutes.
  capillary shock height = 9,75 cm.
- At I_{25}; capillary shock time = 156 minutes.
  capillary shock height = 8,55 cm.

From Figure 3, it can be read the value of capillary shock time and capillary shock height on silty sandy clay soil types as follows :

- At I_5; capillary shock time = 166 minutes.
  capillary shock height = 9,75 cm.
- At I_{15}; capillary shock time = 157 minutes.
  capillary shock height = 8,70 cm.
- At I_{25}; capillary shock time = 151 minutes.
  capillary shock height = 8,10 cm.

From Figure 4 above, it can be read the value of capillary shock time and capillary shock height on sandy, clayey silt soil types as follows :

- At I_5; capillary shock time = 148 minutes.
  capillary shock height = 9,20 cm.
- At I_{15}; capillary shock time = 145 minutes.
  capillary shock height = 8,65 cm.
- At I_{25}; capillary shock time = 139 minutes.
  capillary shock height = 8,05 cm.

Furthermore, to show the differences in capillary shock parameters based on the type of fine-grained soil media, each at the same intensity level, Figure 5, Figure 6, and Figure 7 are presented below :

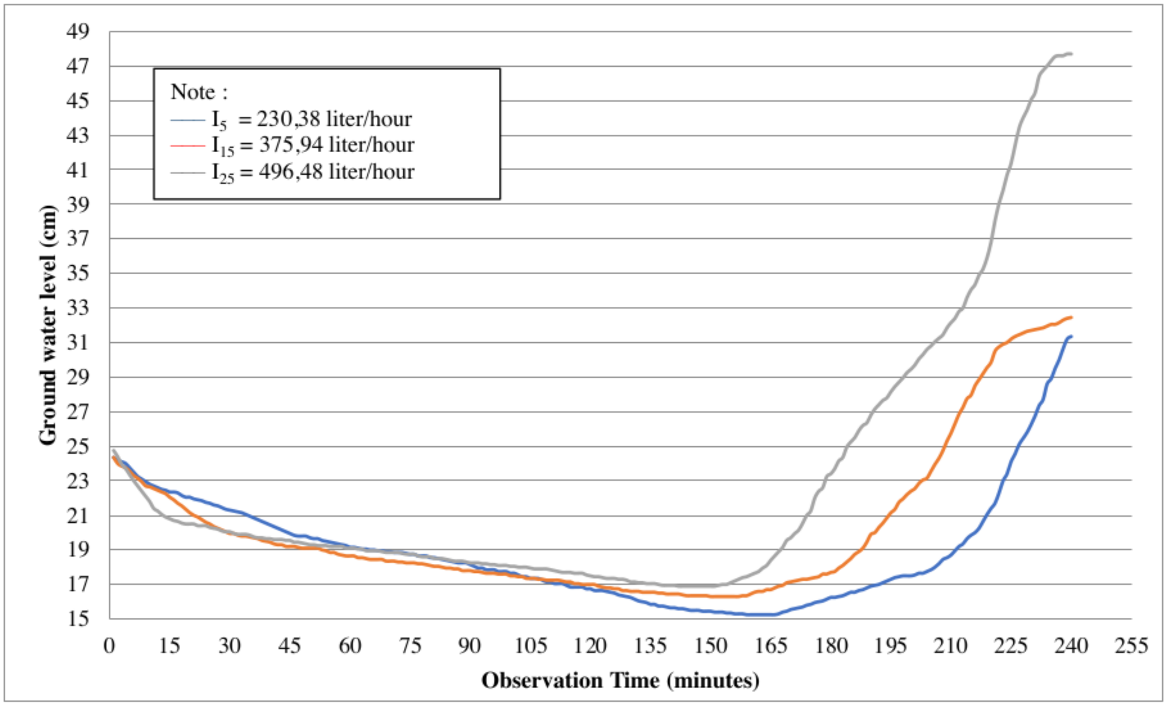

Fig. 3 Groundwater Level Fluctuation on Silty Sandy Clay with Rainfall Intensity Variations I_5, I_{15}, and I_{25}

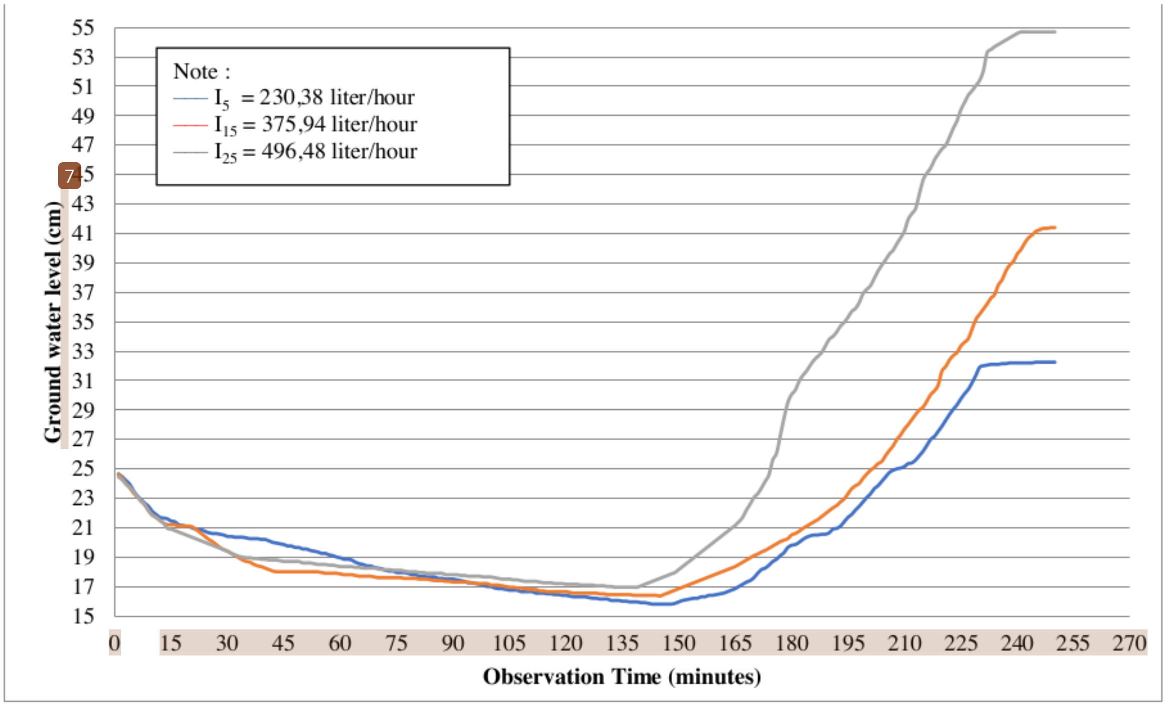

Fig. 4 Groundwater Level Fluctuation on Sandy Clayey Silt with Rainfall Intensity Variations I_5, I_{15}, and I_{25}

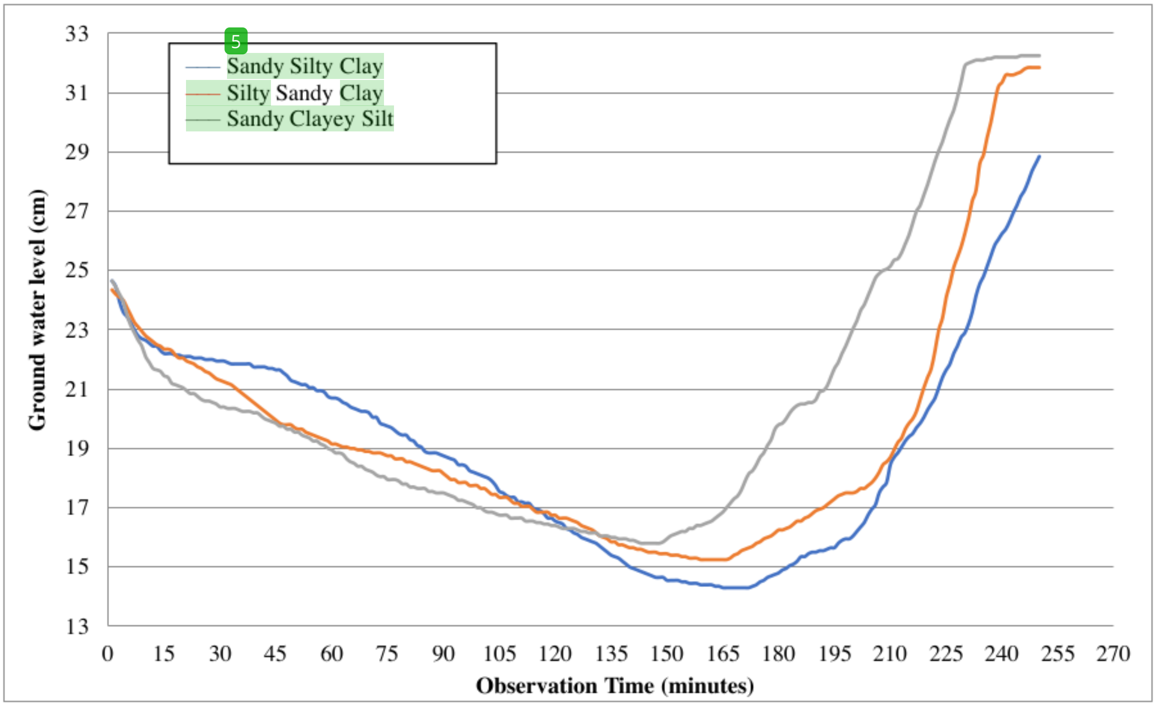

Fig. 5 Groundwater Level Fluctuations in 3 Types of Fine-Grained Soil with Rainfall Intensity I_5

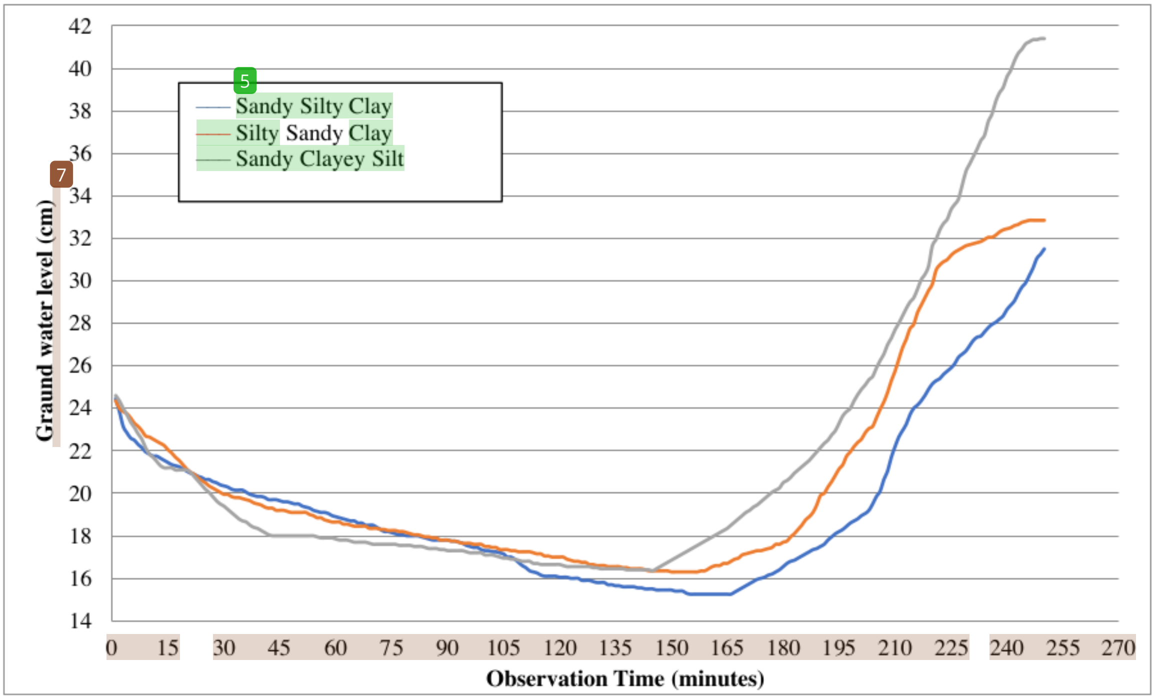

Fig. 6 Groundwater Level Fluctuations in 3 Types of Fine-Grained Soil with Rainfall Intensity I_{15}

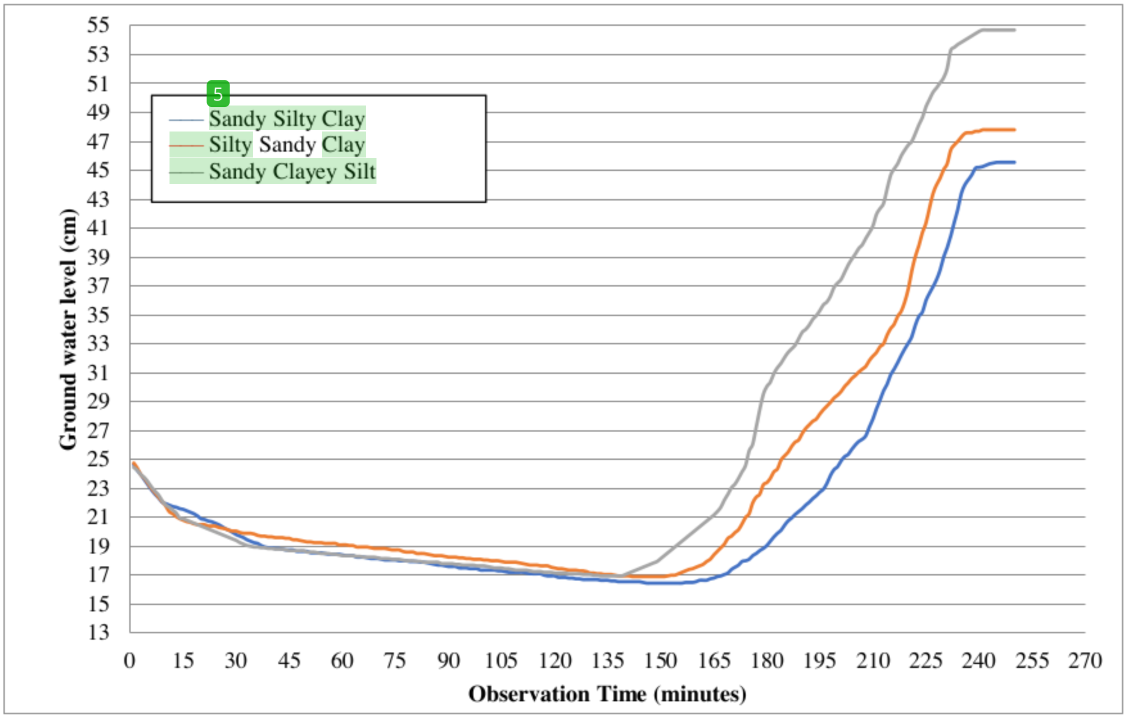

Fig. 7 Groundwater Level Fluctuations in 3 Types of Fine-Grained Soil with Rainfall Intensity I_{25}

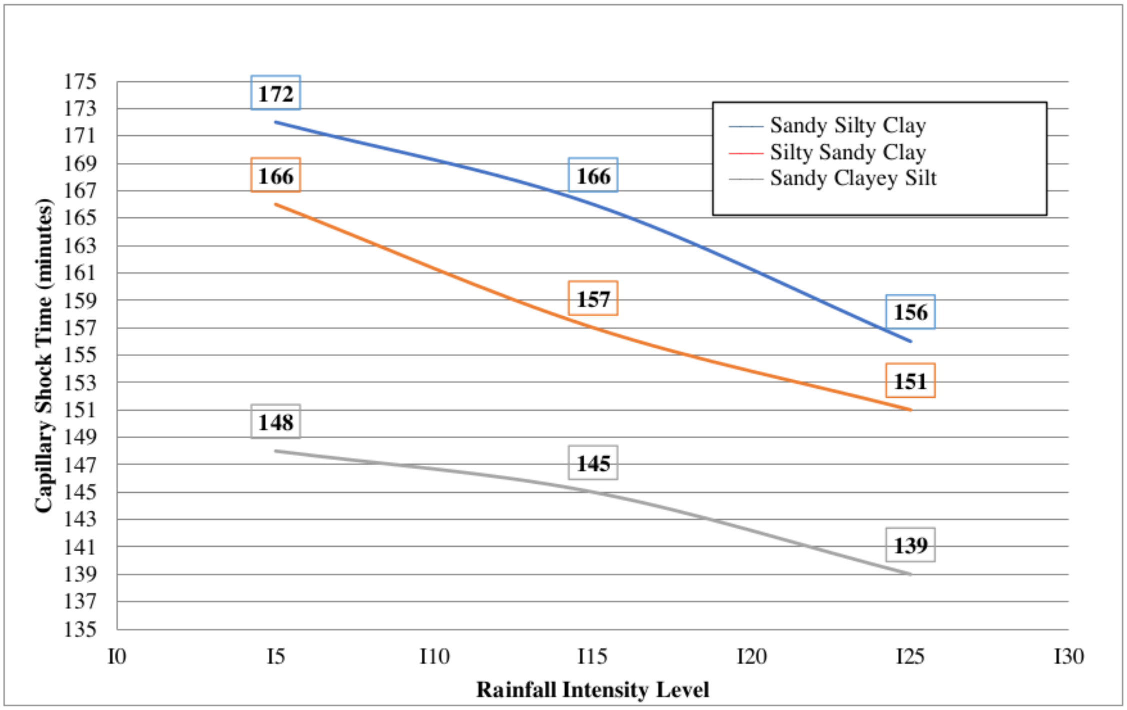

Fig. 8 Relationship of Rainfall Intensity versus Capillary Shock Time (minutes)

3.2. Discussions

3.2.1. Capillary Shock Time

From the results of the above readings on the capillary shock value in each different soil medium and the variations in rainfall intensity, which are also different, the following can describe the effect of these two variables on the capillary shock time parameter in graphical form as follows :

Figure 8 shows that the capillary shock time in a fine-grained soil layer is influenced by two factors, namely: (1) soil particle size and (2) rainfall intensity. The capillary shock time lasts longer when the soil particle size becomes finer. A fine soil particle size will form a smaller pore cavity, so it takes a longer time to increase capillary pressure in the soil layer. This is in line with the opinion of Kosugi (1994), who stated that the pore size distribution could be described as a lognormal distribution function, which is considered sufficient to characterize various types of layers [7].

The intensity of rainfall also significantly affects the duration of capillary shock in fine-grained soil layers. High rainfall intensity will also result in a greater infiltration rate, so the volume of water that percolates into the soil layer and reaches the saturated zone will be even greater. This will cause the phreatic water reserves in the saturated zone to increase immediately, so it will quickly recover the groundwater reserves that are sucked in due to increased capillary pressure. After the water supply from the percolation has restored the groundwater reserve volume, the capillary shock phenomenon will end soon.

3.2.2. Capillary Shock Height

In the same way and from the readings of the capillary shock height values that occur in each different soil medium and the variations in rainfall intensity, which are also different, the following can describe the influence of these two variables on the capillary shock height parameters in graphic form as follows :

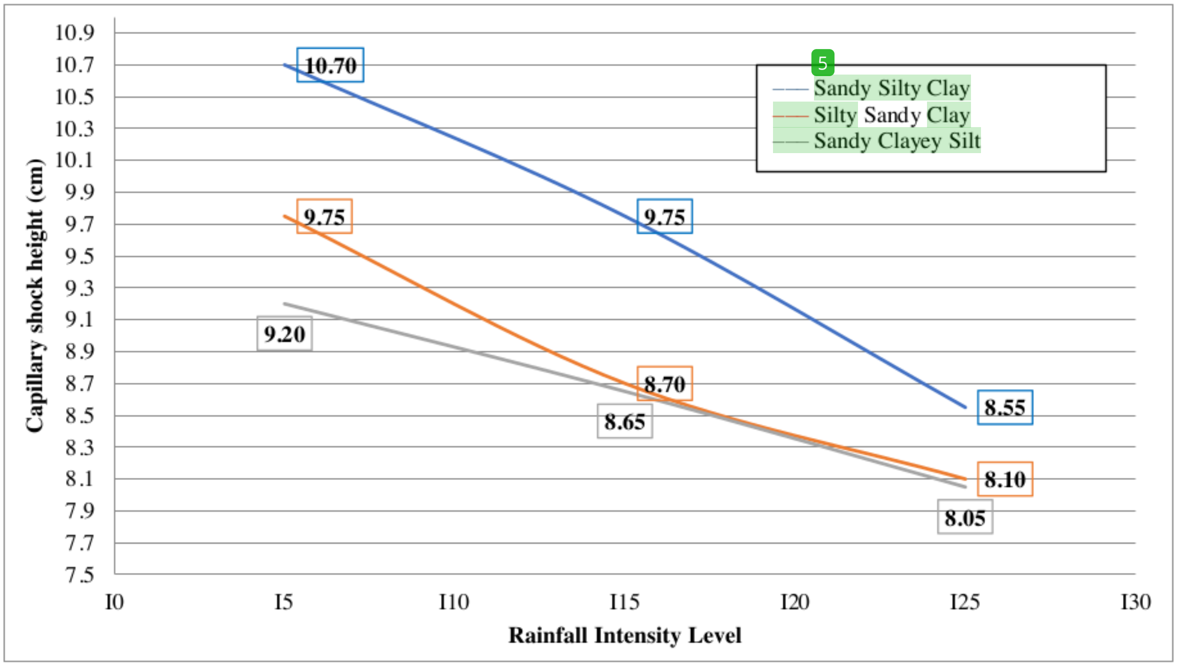

Fig. 9 Relationship of Rainfall Intensity versus Capillary Shock Height (cm)

In Figure 9 above, it can be seen that there is a linear correlation between the capillary shock time parameter and the capillary shock height parameter. The effect of particles on fine-grained soils also affects the capillary shock height parameters. The finer the soil particles, the greater the capillary shock that occurs. This is in line with the opinion of Hansbo (1976) that the finer the soil particles, the higher the capillary pressure [9]. In the soil layer, small particles will result in smaller pore cavities.

Suppose the pore cavity in the soil is identified with a capillary tube. In that case, Young-Laplace's law applies that the smaller the capillary tube diameter, the greater the capillary pressure [12]. It is also supported by Leiv Magne Siqveland and Svein Magne Skjæveland (2021) opinion that the classical Young-Laplace equation describes the relationship between capillary pressure and surface tension and the main radius of curvature between surfaces [13].

Likewise, the intensity of rainfall not only shortens the duration of capillary shock but also significantly affects the parameters of the capillary shock height. The higher the rainfall intensity level, the lower the capillary shock height parameter. This is because the high intensity of rainfall will accelerate and enlarge the supply of percolation water into groundwater reserves in the saturated zone. The large water supply from the percolation process will immediately result in groundwater recovery, and the capillary shock process will stop more quickly. This is relevant to the opinion of Aryana and Kovscek (2013) and Chao et al. (2021) that capillary pressure and relative permeability can be expressed as a function of local phase saturation [15].

4. Conclusion

Based on the results of the discussion above, the authors formulate several conclusions resulting from this study, namely :

1) The effect of rainfall intensity on capillary shock parameters is very significant, both on capillary shock time and on capillary shock height. The higher the intensity of rainfall at the beginning of the rainy season, the shorter the capillary shock time, and the lower the capillary shock height that occurs.
2) Likewise, the effect of fine-grained soil particle size on capillary shock parameters is also very significant, both on capillary shock time and on capillary shock height. The finer the soil particles, the longer the capillary shock time, and the greater the capillary shock height.

Funding Statement

This research was funded by the Ministry of Education and Culture of the Republic of Indonesia through the Basic Research for Higher Education (PDUPT) scheme for the 2022 research budget year.

Acknowledgments

With the completion of the manuscript, the authors need to thank all those who have helped, from the implementation of testing and data analysis to the discussions that took place during this article. The author's first thanks go to all Ministry of Education and Culture of the Republic of Indonesia staff, who have provided research funding assistance.

Likewise to fellow lecturers at Universitas Muhammadiyah Makassar and at the Bosowa University of Makassar, who have provided many inputs and suggestions both in the implementation of laboratory tests and at the time of writing articles. Also, the author feels the need to thank the students who, with all sincerity and sincerity of heart, have helped the author during the process of carrying out the tests in this research.

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