Determination of Hydraulic Conductivity Value by using Sunjoto Shape Factor

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Abstract. Hydraulic conductivity, K value, is important for soil properties determination and there are many equations and method that can be used in this region. In 1951, Hvorslev introduced the shape factor method to determine K value that only depends on geometry of well. The geometry of well or shape factor is mainly focused on the length, screen and base of the groundwater well. Later, many researchers used this method and developed different kind of equations for different geometry of wells. Sunjoto also developed equations and shape factor to determine the K value. This method can be used easily by using iteration method. In this research, the comparison has been performed using constant laboratory test method and Sunjoto method. The experiment test was conducted in the laboratory and it took measurements for three tests. The Sunjoto equation was used for analysis to the experiment test measurements. The hydraulic conductivity value with constant head test is 0.00038 m/sec and with Sunjoto shape factor method is 0.000184 m/sec for test (1), 0.000180 m/sec for test (2) and 0.000119 for test (3). According to this comparison value, the hydraulic conductivity value is more acceptable when it uses shape factor method since the constant laboratory test is using disturb sample. Moreover, according to the result, Sunjoto method can be used as a new method to determine hydraulic conductivity value.

1. Introduction

Hvorslev (1951) first introduced shape factor equations to solve the error of hydrostatic time lag. These equations were developed to determine hydraulic conductivity value by focusing only on the dimension of well area [1]. Following Hvorslev, many scientists have been developed shape factor equations. Many arguments arise about several shape factor equations assumptions [2][3]. Sunjoto developed the equations in unsteady state conditions based on Hvorslev (1951). He modified this equation to compute the drawdown and coefficient of permeability[4][5][6]. In 2002, Sunjoto developed several shape factor formulas as the equation parameters. His method is well known in Indonesia and many researchers have conducted research about this equation and method [7][8]. For example, Runtu Kexia G.A., Sunjoto S., and Hendrayana H. had conducted the research using the Sunjoto equations for comparison with Cooper-Jacob method under pump test [9]. These researches and papers mentioned that Sunjoto equation can be used easily under the pump test. Most of the previous equations, which were based on well formula geometry, were developed for slug test, such as the research of Hvorslev (1951), Cooper et al (1967), and Bouwer and Rice (1971) despite many researches have been used Sunjoto shape factor equation in pump test. Therefore, the researcher tries to prove clearly about kinds of more appropriate well test for Sunjoto equation. The pump test or slug test, which was performed with different kinds of wells, is not easily taken at the field area. According
to this reason the researcher has decided to use experiment tank and well in the Laboratory to do the pump test and slug test. The main part of research usually has been divided into two parts; data analysis under pump test and data analysis under slug test. In this current research, the researcher has chosen to use new shape factor that had been developed by Sunjoto with appropriate well conditions under pump test.

2. Objectives and Methods

The main objective of this research is to prove and decide what kind of aquifer test is more suitable with Sunjoto method to determine the hydraulic conductivity value. The research method includes three parts. In the first part, the researcher had to collect data and researches that were related to the Sunjoto equation and various kinds of well condition geometry. The experiment tank had to be prepared for aquifer demonstration and for the pump test implementation. The grain size analysis test had been done in Laboratory to know the soil materials characteristics. Then, in the second part of research, the constant head test was conducted at the Laboratory and the hydraulic conductivity value from this test had been taken as reference value. In the third part, the researcher tried to perform data analysis using pump test equation. The groundwater drawdown data measurements were obtained by the experiment tank. The experiment test had been conducted for 8 hours for the first test, 12 hours for the second test and more than 14 hours for third test. The analysis was performed later, and it will be done using the well geometry to determine hydraulic conductivity value. The comparison had been done using these three results.

2.1. Characteristics of Soils

The grain size analysis and constant head test were conducted at Laboratory to determine the soils characteristics (Figure 1). According to grain size distribution curve, the Hazen’s effective size of D10 gravel pack is 0.123 mm and the slotted size must be equal to the D10 gravel pack. D10 is the diameter of 10% material grain size [10]. The soil materials that have been used in this test can be determined as fine sand according to the grain size analysis test. The measurement result has been described in Figure 1.

![Grain Size Analysis Curve](image-url)

**Figure 1. Grain Size Analysis Curve**
2.2. Determining hydraulic conductivity value by constant head test

The constant head permeability test is a laboratory experiment to determine the soil permeability. The measurement data can use the following equation in order to get the permeability coefficient, \( k \) [11]. In this research, the permeability was corrected into 20°C (68° F) by multiplying \( k \) using water viscosity ratio at temperature test to the water viscosity at 20°C (68° F). The diameter of specimen is 7.5 cm, area is 44.18 cm\(^2\), and volume is 220.9 cm\(^3\). The average discharge \( q \) is 4.495 cm\(^3\)/sec, Hydraulic gradient \( I \) value is 2.2 and the Correction factor \( R \) is 0.829. The Hydraulic Conductivity \( K \) value is 3.8E-0.4 m/sec based on the constant head test at the Laboratory.

| t (sec) | Manometers | Volume cm\(^3\) | T °C | Q cm\(^3\)/sec |
|--------|------------|----------------|------|----------------|
|        | \( h_1 \) cm | \( h_2 \) cm |      |                |
| 112    | 95.2      | 88.6          | 500  | 28             | 4.464 |
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| 112    | 95.2      | 88.6          | 500  | 28             | 4.464 |
| 111    | 95.2      | 88.6          | 500  | 28             | 4.505 |
| 111    | 95.2      | 88.6          | 500  | 28             | 4.505 |
| 111    | 95.2      | 88.6          | 500  | 28             | 4.505 |

3. Sunjoto well shape factor

Shape factor is a value that serves as diameter of casing, length of perforated casing, base condition of casing (permeous or impervious), the tip of casing position to the layer position of aquifer, and confined or unconfined aquifer [12]. In 1988, Sunjoto developed a formula to calculate the recharge system dimension under unsteady flow conditions. Sunjoto modified this formula and developed shape factor as the parameter of this equation in order to determine hydraulic conductivity of soils in 2002 and 2014 [13].

\[
S = \frac{Q}{FK}
\]  

(1)

Where: \( K \) = hydraulic conductivity (m/s), \( Q \) = discharge (m\(^3\)/s), \( F \) = shape factor (m), \( s \) = drawdown (m). The \( F \) parameter of Sunjoto equations represents the well conditions of geometry. Once the research has been conducted, this equation proves that drawdown and hydraulic conductivity value can be computed without graphic and complicated method. Sunjoto continuously developed the \( F \) well shape factor under various kinds of well condition. The shape factor \( F \) for unconfined aquifer is:

\[
F = \frac{2\pi L}{\ln\left(\frac{L+2r}{r}\right) + \left(\frac{r}{L}\right)^2 + 1}
\]  

(2)

Where: \( L \) = Length of the Screen (m), \( r \) = Radius of Well (m), \( F \) = shape factor (m). As it is known as a new formula, this shape factor equation needs to be proved using appropriate well conditions. In this research, the researcher used this equation under unconfined aquifer with pump test.

4. Data analysis by shape factor

The pump recharge (full penetration) test (1) has been conducted on May (10), 2019 for (8) hours, the test (2) has been conducted on May (12), 2019 for (12) hours, and test (3) on May (14), 2019 for more
than (14) hours at Hydraulic Lab, Department of Civil and Environmental Engineering, UGM. The discharge rate \( Q \) is 0.000389105 m³/minutes for each test. In this test, the initial thickness is 0.608 for test (1), 0.359 for test (2), and 0.355 for test (3). The screen length also 0.3 m for test (1) and 0.15 m for test (2) and test (3) (Table 2). According to the Sunjoto method, shape factor value has to be used to determine hydraulic conductivity value. The well geometry is important in order to have accurate calculation. The Hydraulic Conductivity value can be determined using iteration method in Sunjoto shape factor equation. Total value of the last ten values were taken and served as the average value and determine the \( K \) value. According to this calculation, the \( K \) value is 0.000131 m/sec in test (1), 0.0001809 m/sec in test (2) and 0.000119 for test (3) respectively.

5. Results and Conclusion

In this research, the researcher has performed comparison to the hydraulic conductivity value using constant head test and Sunjoto method. The comparison result is acceptable despite of a little difference between disturbed sample and un-disturbed sample (Table 2 and Figure 2). The shape factors in Sunjoto equation have to be used correctly in this analysis. Many researchers developed the shape factor equations on different well conditions. The shape factor equations for unconfined aquifer have been used in this research, and Sunjoto developed this equation under full penetration test in unconfined aquifer. The calculation of shape factor value shows two different results that based on well geometry (length and radius of well). The \( K \) value has the same result under pump test despite of the use of different shape factor values. There have some types of error as conditional error, computational error and the assumptions of formula error even though the result can be assumed Sunjoto shape factor equation can be used to determine hydraulic conductivity value under pump test. According to these reasons, the researcher will try to do data analysis using Sunjoto shape factor equation under slug test in the future as described in the introduction part.

Table 2. Comparison of hydraulic conductivity value by constant head test and Sunjoto equation

| No | Pump Recharging Test | \( Q \) (Discharge Rate) (m³/min) | Screen length (m) | Initial Thickness (m) | Hydraulic Conductivity Value (m/sec) |
|----|----------------------|---------------------------------|------------------|----------------------|-------------------------------------|
|    |                      |                                 |                  |                      | Constant Head Test | Sunjoto Method                     |
| 1  | 10-May               | 0.000389105                     | 0.3              | 0.608                | 0.00038             | 0.000131434                        |
| 2  | 12-May               | 0.000389105                     | 0.15             | 0.359                | 0.00038             | 0.0001801                          |
| 3  | 14-May               | 0.000389105                     | 0.15             | 0.355                | 0.00038             | 0.00011966                         |

Figure 2. Comparison Graph of \( K \) value by Constant head test and Sunjoto Method
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