Multiple Analyses for Hydraulic Conductivities Identification in Clay Aquifer

Sabariah Musa*, Nor Azazi Zakaria**, Lau Tze Liang**
* Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia
** River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Malaysia
Corresponding Author: sabawater@gmail.com

Abstract— A high water table requires defined and new approaches to solve non-direction flow of surface and ground water movement. This paper presents the analysis to determine the hydraulic conductivity approaches used for the unconfined layer. It discusses the techniques applied to groundwater flow or hydraulic conductivity through drilling well method. It was found that the hydraulic conductivity values for Sri Gading for silty clay or clay aquifer is in the range from 0.0001 m/day to 0.086 m/day. This indicates the relationships of surface and sub-surface parameters through quantitative evaluations of groundwater responses. Data distribution is a prerequisite for ground water management and also for properties identification.

Keywords—hydraulic conductivity; unconfined; groundwater; clay area

I. INTRODUCTION

Frequency records are important data for case analysis and simulations. The yearly records [1] show an accumulated rainfall depth of more than 1,000 mm for three years. In 2010, the accumulated rainfall exceeded 2,000 mm. The monthly rainfall depths also fluctuate and range from 500 mm to 2,500 mm. Then, this area study categorized as saturated surface cause by clayed condition and flatten area. The chosen case failure by stormwater movement to channel into ground during wetted season [2]. Many factor was occurs the problems, the one of the properties is hydraulic conductivity was related to water movement in the soil or ground.

This study focus on hydraulic conductivity because it is one important of the properties of aquifers in hydrogeology as the values found in nature [3]. To date, no study has comprehensively compiled hydraulic conductivity or permeability assessments for unconfined aquifers under clay conditions because it the most complex and nature [4,5]. Therefore, the purpose of this paper is to compile the hydraulic conductivity data and to estimate the hydraulic properties of the aquifer. The results of the compilation analysis and a general discussion for every data set are presented.

The relative properties of this area commonly used for water management purposes. This condition does not define the flow direction of underground water movement. The water for clay area is steady and remains in the aquifer without recharging and discharging if nothing moves it. Then, the amount of moisture that will eventually reach the water table is defined as the natural ground water recharge. Once, the hydraulic conductivity and transmissivity eventually behalf of drainage system in the ground [1]. Therefore, the recharge amount depends on the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth, and the soil type.

Water that has remained in the ground for long periods has good treatment and fresh natural conditions for water distribution purposes. But, water quantity purpose according hydraulic properties had poor aquifer and low flow in clay layer. Thus, the contribution from the ground to the surface is the point of conflict of recharge, and it conveys the surface to the ground pond to recycle the water in normal situations. Then, these evaluations hopefully become best prediction for any water management purpose for surface and subsurface flow especially for clay aquifer in the ground system.

II. COMBINED APPROACH

The extreme records shown in fig. 1 was explained all the tests and methods used. The pumping test is the main analysis used by the current study to define the hydraulic characteristics. The drawdown observation method was manually used occasionally to characterize the flow rate for the multiple-step analysis. Data were recorded once a year from January 2011. Sampling and wells was constructed 4 wells (Well 1 - W1, Well 2 - W2, Well 3 - W3 and Well 4 - W4) around 35m for the study area. The analysis depends on the situation and the weather for suitable simulations. Rainfall runoff applications for the real data are not time limited, but other methods were selected because man-made surface water runs the model smoothly without wasting testing time.
B. Sieve Analysis Distribution

Grain size analysis is part of the empirical approach to determine the hydraulic conductivity parameter. Three methods were used for analysis. The dry sieve method was conducted on the samples from W1 that were categorized for four types of soil, gravel, sand, silt, and clay. This samples was analyzed using dry and wet sieve classification methods. The distribution for both standards had more clay, followed by silt for the whole layer. However, a little sand appeared on top and more appeared at the bottom layer below 20 m in aquifers. However, this area dominated by clay and bit of sandy and gravel, sometimes it shows that the whole layer has own perspective value as a potential and aquifer for both of water function.

The CILAS method, which is an optional application, was used at the W3 and W4 classification types. It was selected based on the clay and silt content to give some accuracy in the classes. These site records with more clay and constant minimum silt and sand below 15% of the pass. W4 was distributed by the strata for the whole layer, which was dominated by clay, silt, and sand. These conditions are categorized as a fine layered or clayey aquifer in the deep layer until 45 m below the mean sea level.

Hydraulic conductivity refers to groundwater movement through the voids within the soil. Soils with large voids (sand or gravel) are generally more permeable than those with small voids like clay or silt. Thus, permeability increases with void ratio. According [6] derives the hydraulic conductivity from grain size analyses by the empirical formula;

\[ K = a(D_{10})^b \]  

where

- \( a, b \) = empirically derived terms based on the soil type
- \( D_{10} \) = the diameter of the 10 percentile grain size of the material

Sometimes, for dense or compacted sand, the coefficient of permeability can be obtained using the following equation proposed [7]. Table II shows the computed values for all the samples from W3.

\[ K = 0.35D_{15}^2 \]  

where

- \( K \) = the coefficient of permeability
- \( D_{15} \) = the soil particle diameter corresponding to 15% passing of the grain size distribution.

Using Equation (2) yields the sample solution for the analysis distribution of 1.5 m deep soil. Based on the CILAS graph, \( D_{15} \) is 1.8 \( \mu \)m for the soil distribution is \( K \) = 1.134 \( \mu \)m or 0.098 m/day. The simulation data for the
wells are shown in Table III and the average permeability at this location is approximately 0.075 m/day.

### TABLE III. HYDRAULIC CONDUCTIVITY OUTPUT FOR ALL WELLS THROUGH THE CILAS ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.082</td>
<td>0.086</td>
<td>0.056</td>
<td></td>
</tr>
</tbody>
</table>

### C. Permeability Effects

Permeability shows the anisotropy of permeability tension according to geological observations. Horizontal permeability is systematically higher than vertical permeability. This result is consistent with many horizontal predictions of well performance, and it can be used to predict future groundwater availability in wells.

Based on laboratory tests using the falling head, permeability is normally slow at an average of $K = 2.515 \times 10^{-7}$ m/s @ 0.026 m/day. Fig. 2 shows the different permeability values at different levels and soil sizes. The test analysis was based on the type of soil application. Soil type was clay in the dominant layers. The result was computed using the following equations:

$$h_2^2 - h_1^2 = \frac{Q}{\pi K} \ln \left( \frac{r_2}{r_1} \right)$$  
(3)

$$K = \frac{Q}{\pi (h_2^2 - h_1^2)} \ln \left( \frac{r_2}{r_1} \right)$$  
(4)

### D. Falling Head Tests

This sample estimation was performed using Equation (5) at the W2 sample points at a depth of 25.5 m. The simulation average from the falling head tests is $K = 2.515 \times 10^{-7}$ m/s @ 0.026 m/day, for permeability in W2. For example, the sample area, $A = 2375.83$ mm², standpipe area, $a = 59.72$ mm², time ($t$) = 3 hours 49 min 7s, $h_1 = 128$ cm and $h_2 = 112$ cm.

$$K = \frac{2.303A}{1000 \times A \times 60 \times \log_{10} \frac{h_1}{h_2}}$$  
(5)

### E. Loadtrack Machine Analysis

This test was conducted on the undisturbed samples with 55 mm or 56 mm diameter and 100 mm height to run the permeability parameters using the automatic system on a loadtrack machine (Fig. 3). All samples were run from 3 days to 9 days to finish the loading based on the particle sizes of the samples. The detailed results of the layers were analyzed every 1.5 m from top soil to 30 m deep. Based on the computed automatic analysis, permeability is approximately $K = 0.01$ m/day for the W3 point.

### F. Consolidation Response

This test analysis was conducted on samples with 50 mm diameter and 20 mm thickness from undisturbed soil. Every layer was handled carefully and run by loadtrack
machines. The samples from W3 were used. Consolidation rate is a function of the permeability of the soil. The coefficient of permeability \( K \) was indirectly obtained from the soil samples based on the results of the load test and the oedometer tests (W1) as follows:

\[
K = \frac{C_v \gamma_w a}{1 + e_o} = C_v \gamma_w m_v
\]

where

\[ C_v = \text{coefficient of rate of consolidation (m}^2/\text{year@m}^2/\text{sec}) \]

\[ \gamma_w = \text{unit weight of water (kN/m}^3) \]

\[ m_v = \text{coefficient of volume compressibility (m}^2/\text{MN}) \]

\[ a_v = \text{coefficient of compressibility} \]

\[ e_o = \text{initial void ratio, } e_o = \left( \frac{H_w - H_s}{H_s} \right) \text{ and } H_s = \frac{W_s}{AG_v} \]

\[ H_s = \text{equivalent thickness of solids} \]

\[ W_s = \text{dry weight} \]

\[ A = \text{area} \]

\[ G_v = \text{specific gravity of the solid} \]

According to the fluctuations of the compression index \( C_v \) and the preconsolidated load \( P_o \) in fig. 4, both parameters had similar actions in the layers, and the soil in the layers were consolidated and less compressible than that in the original condition. This one-dimensional test shows higher compressions in the sandy layer of the middle and bottom layers, which contain fine to medium sand and some gravel.

G. Infiltration Record

A surface study [8] was conducted and analyzed using the infiltration rate test with an infiltrometer in the selected sites. The results from these studies were used to estimate the hydraulic conductivity actions. The simple estimation generally uses small-scale methods to identify water movement on the surface. This sample solution was obtained from station 9: RECESS, UTHM, for the hydraulic conductivity parameters shown in fig. 6 with average of \( K = 1.152 \times 10^{-2} \text{ mm/sec at } 0.01 \text{ m/day} \) and average of infiltration rate \( = 9.78 \text{ mm/hr (silty clay)} \).

Table IV presents the summary of the Infiltration tests that were conducted on the surfaces of 10 locations. The average value is \( K = 0.011 \text{ m/day} \). This location is
dominated by silty clay, with low infiltration and hydraulic conductivity for natural runoff. The simulations were acceptable in the area conditions, as low runoff was absorbed on the ground in the deep aquifer layer.

<table>
<thead>
<tr>
<th>Station</th>
<th>Infiltration rate (mm/hr)</th>
<th>Hydraulic conductivity (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parit Daun</td>
<td>11.4</td>
<td>$1.6944 \times 10^4$</td>
</tr>
<tr>
<td>Parit Rappan</td>
<td>15</td>
<td>$1.667 \times 10^4$</td>
</tr>
<tr>
<td>Parit Sempadan</td>
<td>11.22</td>
<td>$6.583 \times 10^4$</td>
</tr>
<tr>
<td>Parit Karjo</td>
<td>7.8</td>
<td>$1.944 \times 10^4$</td>
</tr>
<tr>
<td>Parit Raja Town</td>
<td>9.84</td>
<td>$1.2083 \times 10^4$</td>
</tr>
<tr>
<td>Parit Jelutong</td>
<td>12.3</td>
<td>$1.708 \times 10^4$</td>
</tr>
<tr>
<td>Parit Haji Rais</td>
<td>11.82</td>
<td>$2.333 \times 10^4$</td>
</tr>
<tr>
<td>Block G3B. UTHM</td>
<td>10.548</td>
<td>$1.914 \times 10^4$</td>
</tr>
<tr>
<td>RECESS, UTHM</td>
<td>9.78</td>
<td>$1.152 \times 10^4$</td>
</tr>
<tr>
<td>Block C5, UTHM</td>
<td>13.2</td>
<td>$2.208 \times 10^4$</td>
</tr>
</tbody>
</table>

Average $K = 1.282 \times 10^{-2}$ mm/s @ 0.011 m/day

IV. CONCLUSION

The findings of the tests and analyses can be used to estimate and evaluate the related area condition. Soil and water samples and rainfall data were used to validate the surface and sub-surface conditions. Samples and tests were selected from the limited samples to be analyzed. Therefore, some samples were used for selected tests to represent the condition of the entire area. Based on the high water table surrounding the area, the depth of the water table in the region varies, with fluctuations from 0.3 m to 2.00 m between the pre-monsoon and post-monsoon periods [9].

Hydraulic conductivity was related to the test type, and the surrounding parameters were related to soil type in the layers. The hydraulic conductivity or permeability values for the areas in Sri Gading with silty clay or clay aquifer ranged from 0.0001 m/day to 0.086 m/day for all surfaces and sub-surfaces. This relative properties was unconsolidated clay and organic as layered clay with poor aquifer for water flows. According to evaluation measured, side effect of the hydraulic parameters were analyzed through the pumping method commonly effected by well’s design such as screening sizes, pump capacity, and casing sizes. Thus, combination of these methods useful for valuation study and reasonable used for design and application cases. The general effects from environmental and design should be considered to conclude the situation and suitable application for the groundwater management purposes.

ACKNOWLEDGMENT

Authors thank the Universiti Tun Hussein Onn Malaysia, Johor and Universiti Sains Malaysia, Pulau Pinang which has supported exchange of expertises. The study was partially funded by ERGS, Universiti Tun Hussein Onn Malaysia.

REFERENCES