

A METHOD TO ANALYZE THE HYDRAULIC CONDUCTIVITY OF WATER INFILTRATION INTO TWO LAYERED SOIL WITH HYDRUS 2D/3D

SUATU METODE UNTUK ANALISIS KONDUKTIVITAS HIDRAULIK INFILTRASI AIR KE DALAM TANAH BERLAPIS DUA DENGAN HYDRUS 2D/3D

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ABSTRACT

A method was proposed to analyze two dimension hydraulic conductivity of water infiltration into layered soil consist of Manado soil over sand bentonite (5%) soil with HYDRUS software 2D/3D. The Manado soil (loamy sand) was classified with USDA soil standard. Sand Bentonite (5%) was analyzed with Soil Water Characteristic Curve (SWCC) and by using van Genuchten formula to analyze the properties of soil such as residual water content (θ_r), saturated water content (θ_s), fitting parameter n , l and α . HYDRUS software 2D/3D was used to compute the two dimensional of water infiltration into a vertical column 1cm x 100cm of two layered soil consist of Manado soil over sand- bentonite(5%) soil. Pounded infiltration is initiated with a zero pressure head at the soil surface, while free drainage is used at the bottom of soil profile. The water infiltration into the soil was measured for fifty days. The change of water content (θ), pressure head (H) and hydraulic conductivity (K) along the fifty days (time) were measured for each of soil at observation depth N-80cm and N-20cm of vertical column layered two soil . A method (fitting curve line) was applied to the relationship between hydraulic conductivity and pressure head as well as hydraulic conductivity and water content which is computed with HYDRUS 2D/3D software. The fitting line curve equation was proposed as a new method to analyze the hydraulic conductivity (K) of two layered soil consist of Manado soil and sand Bentonite (5%) soil in a vertical soil column.

Keywords: hydraulic conductivity, manado soil, pressure head, sand bentonite soil, water content

ABSTRAK

Suatu metode dibuat untuk menganalisis konduktivitas hidraulik dua dimensi pada infiltrasi air dalam tanah berlapis dari tanah Manado di atas pasir bentonite (5%) dengan perangkat lunak HYDRUS 2D/3D. Tanah Manado (*loamy sand*) diklasifikasikan dengan USDA *standard soil*. Pasir bentonite (5%) dianalisis dengan *Soil Water Characteristic Curve* (SWCC) dan menggunakan *van Genuchten formula* untuk menganalisis sifat yang melekat pada tanah seperti kadar air residual (θ_r), kadar air jenuh (θ_s), *fitting parameter* n , dan α . HYDRUS 2D/3D digunakan untuk menghitung infiltrasi air dua dimensi ke dalam kolom tanah arah vertikal pada tanah berlapis dua padatnaha Manado di atas pasir bentonite (5%). Terjadinya infiltrasi dimulai dengan suatu tinggi tekanan sama dengan nol di atas permukaan tanah, sementara itu, aliran pembuangan bebas berada pada dasar dari profil tanah. Infiltrasi air ke dalam tanah diukur selama 50 hari. Perubahan kadar air (θ), tinggi tekanan (H) dan konduktivitas hidraulik (K) selama 50 hari diukur setiap kedalaman tanah N-80 cm dan N-20 cm pada kolom vertikal tanah berlapis dua. Suatu metode (*fitting curve line*) digunakan untuk mengetahui hubungan antara konduktivitas hidraulik dengan tinggi tekanan dan juga konduktivitas dan kadar air yang dihitung dengan perangkat lunak HYDRUS 2D/3D. Persamaan *fitting curve line* diusulkan sebagai sebuah metode baru untuk analisis konduktivitas hidraulik (K) pada tanah berlapis dua di tanah Manado dan tanah berpasir bentonite (5%) dalam arah kolom vertikal tanah.

Kata-kata kunci: konduktivitas hidraulik, tanah Manado, tinggi tekanan, tanah berpasir bentonite, kadar air

INTRODUCTION

Infiltration has long been a focus of geotechnical problem such as slope stability, erosion and also in agriculture and water research because of its fundamental role in land-surface and sub-surface hydrology. A large number of mathematical models have been developed to evaluate the computation of infiltration. The Richards equation was derived using the mass conservation law and Darcy's law (Lei et al., 1988). As a physically based numerical model, the Richards equation has been extended into many complex conditions (Brunone et al., 2003), (Pachepsky et al., 2003) and (Barontini et al., 2007). However, the Richards equation is strongly non-linear and cannot be solved analytically, especially under complex initial and boundary conditions. Consequently, numerical methods such as finite difference and finite element methods have been used to solve Richards equation (Arampatzis et al., 2001). The numerical solution of Richards equation requires an iterative implicit technique with fine discretization in space, which results in tedious solving process

(Damodhara Rao et al., 2006). Based on finite element method, the HYDRUS-1D and 2D/3D code was developed to solve the Richards equation and was widely used to simulate one-dimensional and two-three dimensional water movement in variably saturated media (Simunek et al., 2005). The objectives of this study is to propose a method (fitting curve line) to analyze the hydraulic conductivity (K) two dimensional infiltration of water into two layered soil consist of Manado soil and sand Bentonite 5% soil based on the result computing with HYDRUS-2D/3D.

MODEL TEST

Two type of soil were used in this analysis. Manado soil was taken from Manado city in Indonesia. Some test to compute the physical and mechanical properties of Manado soil such as sieve size analysis, specific gravity, unit weight and water content were done in the laboratory. Manado soil was loamy sand based on USDA soil standard test. The physical and mechanical

properties of sand Bentonite mix soil are conducted by Dev Raj Pokhrel (2009). Bentonites are special type of clay which falls on the category of monmorillonite. Bentonite deposit has two forms, Na-monmorillonite or Ca-monmorillonite or both. They have cat-ion exchange capacity; the swelling behavior due to adsorption of water molecules at interlayer cations and at mineral surface. Sodium bentonite is referred to as swelling clay, which has single water layer particles containing Na⁺ as the exchangeable ion. Bentonite has excellent water absorption capacity, which is much higher than ordinary clays. When the sodium Bentonite gets saturated, its volume increases approximately 14 times greater than that of its original volume. The sodium Bentonite is commercially available in the market in the name of "Natural Gel". Sample is prepared by taking a sand- Bentonite mixed soil (5%). Bentonite, with initial volumetric water content 0.49 in a consolidation steel ring which is then directly placed in a SWCC device for the test. No special method of sample preparation is done for sand Bentonite soil. The data obtained from laboratory tests were computed with HYDRUS 2D/3D software. The laboratory test data were percentage of sand, percentage of silt, volumetric water content at 33 kPa, and volumetric water content at 1500 kPa. The physical and mechanical properties of Manado soil and sand Bentonite mix soil were shown in Table 1. And Tabel 2.

Table 2. Physical and Mechanical Properties of Soil

Jenis Tanah	Initial Water Content	Residual Water Content	Saturated Water Content	Saturated Hydraulic Conductivity
	θ (%)	θ _r (%)	θ _s (%)	K _s
Manado Soil	1.85	0.057	0.410	350.2
Sand Bentonite (5%) Soil	49	0.01	0.485	0.006205

Table 2. Physical and Mechanical Properties of Soil

Type of Soil	Sieve size Analysis	Specific Gravity	Unit Weight	Coef. of Permiability		
	% Sand	% Silt	% Clay	G _s	e	
Manado Soil	85.3	13	1.7	2.34	1.1	-
Sand-Bentonite (5%) Soil	92	5	3	2.65	1.3	2.06E-10

MODELING WITH HIDRUS-2D/3D

Bentonite soil is not included in the Hydrus 2D/3D in soil hydraulic parameter. Indirect method was used to provide the initial water content θ_r , saturated water content θ_s , α , m and n (empirical parameters). The soil water retention curves were measured with pressure-plate method by Dev Raj Pokhrel, (2009). The measured results were fitted to the retention curve equations proposed by van Genuchten (1980) and Brooks and Corey (1964) with the RETC code developed by van Genuchten et al. (1991). The equation of van Genuchten model is described as (van Genuchten, 1980),

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(1 + |\alpha h|^n\right)^{-m} \quad h > 0 \quad (1)$$

$$\theta = \theta_s \quad h \leq 0 \quad (2)$$

where h is the soil water pressure head (cm), θ is the water content (cm³/cm³), θ_r and θ_s are the residual and saturated water contents (cm³/cm³), respectively, α , m and n are empirical parameters and $m=1 - 1/n$.

The equation of Brooks-Corey model is (Brooks and Corey, 1964)

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(\frac{h a}{h}\right)^\lambda = \left(\frac{1}{\alpha' h}\right)^\lambda \quad \alpha' h > 1 \quad (3)$$

$$\theta = \theta_s \quad \alpha' h \leq 1 \quad (4)$$

where α' is an empirical parameter (1/cm) and it is the reciprocal of h_a , h_a is often referred to as the air entry value (cm), and λ is the pore-size distribution parameter affecting the slope of the retention function. The fitting results indicated that the measured soil water retention curves were well described by the van Genuchten model. In this case, the unsaturated hydraulic conductivity of each soil layer can be expressed as (van Genuchten et al., 1991).

$$K(h) = \frac{K_s \left\{1 - (\alpha h)^{mn} \left[1 + (\alpha h)^n\right]^{-m}\right\}^2}{\left[1 + (\alpha h)^n\right]^{ml}} \quad (5)$$

where K_s is the saturated hydraulic conductivity and l is an empirical parameter found to be equal to 0.5 for most soils. The corresponding soil hydraulic parameters of each soil are shown in Table 3. The air entry value h_a was obtained from Brooks-Corey model (Table 3).

Table 3. Soil hydraulic parameters of each soil

Name of Soil	n	l	α
Manado Soil	2.28	0.5	0.124
Sand Bentonite (5%) Soil	2.725	0.5	0.0045

The HYDRUS-2D /3D code was based on the one-dimensional Richards equation to simulate water movement in variably saturated media, and the equation was solved by numerical method (Šimůnek et al., 2005). The basic water movement equation was described as,

$$\frac{\partial \theta(h,t)}{\partial t} = \frac{\partial}{\partial z} \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right] \quad (6)$$

where h is the soil water pressure head, θ is the volumetric water content, t is time, z is the vertical coordinate with the origin at the soil surface (positive upward), and $K(h)$ is the unsaturated hydraulic conductivity determined by Eq. (5). For the initial condition and upper boundary condition were,

$$h(z,0) = h_i(z) \quad (7)$$

$$h(0,t) = h_0 \quad (8)$$

where $h_i(z)$ is the initial soil water pressure head through the soil column, and h_0 is the soil water potential at soil surface. The free drainage was to be considered as lower boundary condition,

$$\frac{dh}{dz} = 0 \quad (9)$$

HYDRUS 2D/3D software was used to analyze the hydraulic conductivity (K) of two dimensional infiltration of water into 1cm x 100cm vertical column for Manado soil and sand-bentonite(5%) soil. Pondered water infiltration is initiated with a zero pressure head at the soil surface as shown in Figure 1. as follow,

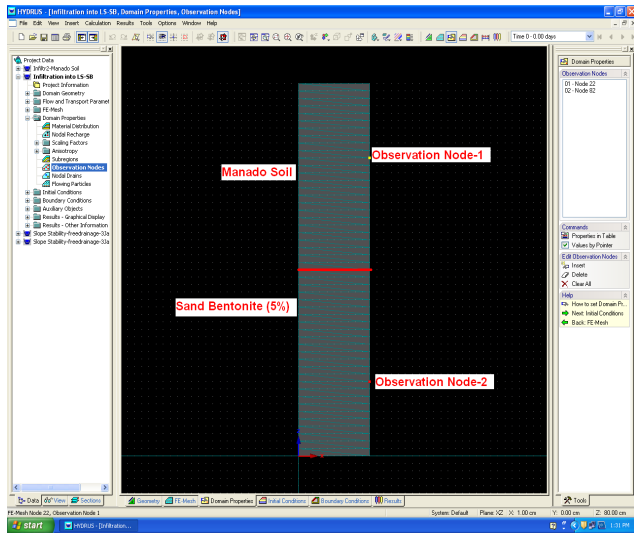


Figure 1. Modeling of soil in HYDRUS 2D/3D

ANALYSIS OF RESULTS

The HYDRUS 2D/3D program was used for modeling of two layered soil in a column and computed for 50 days infiltration of water. The change of water content (θ) for 50 days was shown in Figure 2. as follow,

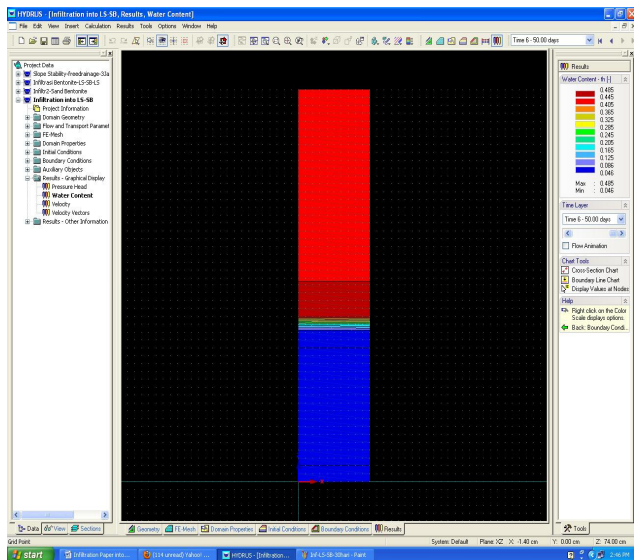


Figure 2. Water content (θ) for 50 days

Hydrus 2D/3D also compute a relationship between hydraulic conductivity (K) and water content (θ) as well as hydraulic conductivity (K) and pressure head (h) of two layered soil at observation node N=80cm (Manado soil) and N=20cm (sand Bentonite soil) as shown in Figure 3. and Figure 4.

To analyzed the hydraulic conductivity (K) of two layered soil in a column, the new fitting curve line was applied directly to the graph (Figure 3. and Figure 4.) for relationship between hydraulic conductivity (K) and water content (θ) also hydraulic

conductivity (K) and pressure head (H) of each soil layer as shown in Figure 5. and Figure 6.

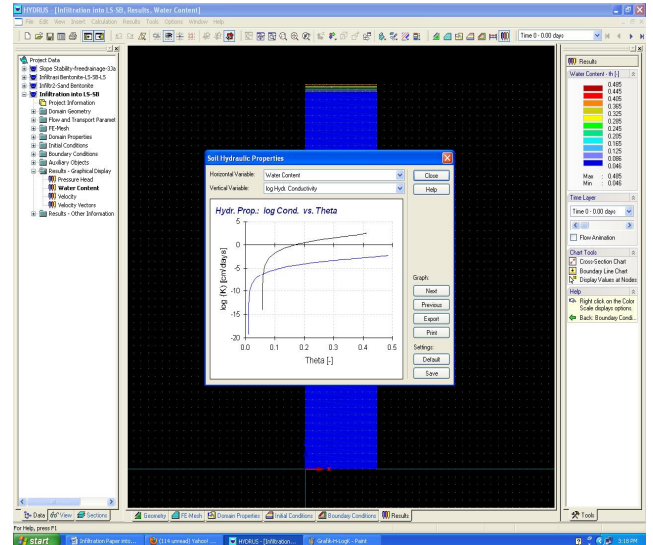


Figure 3. Relationship between Hydraulic Conductivity (K) and Water Content (θ) of each layered at observation node

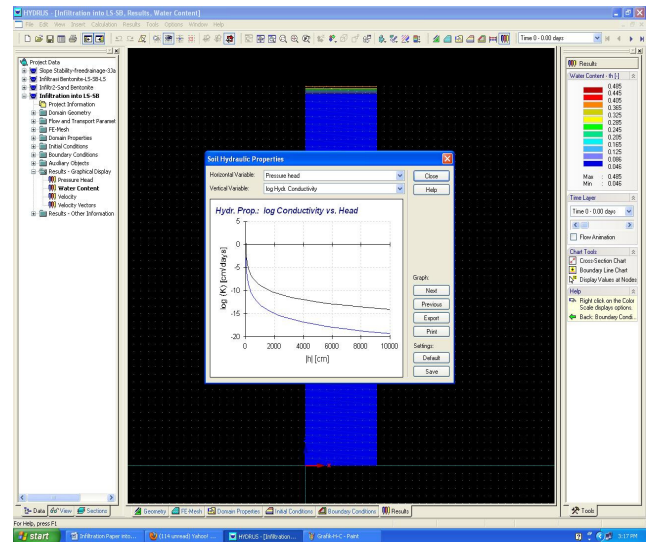


Figure 4. Relationship between Hydraulic Conductivity (K) and Pressure head (H) of each layered at observation node

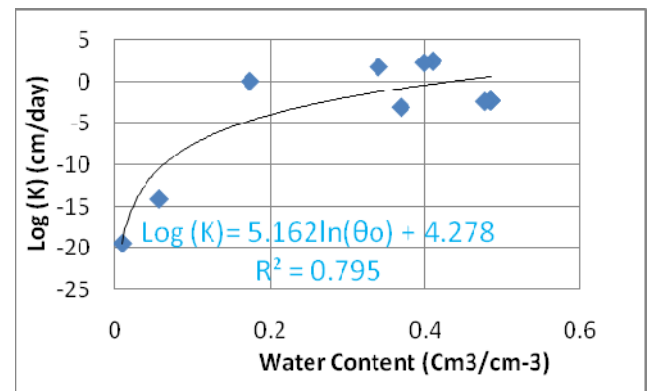


Figure 5. Relationship between Hydraulic Conductivity (K) and Water content (θ) of two layered soil computed with fitting line

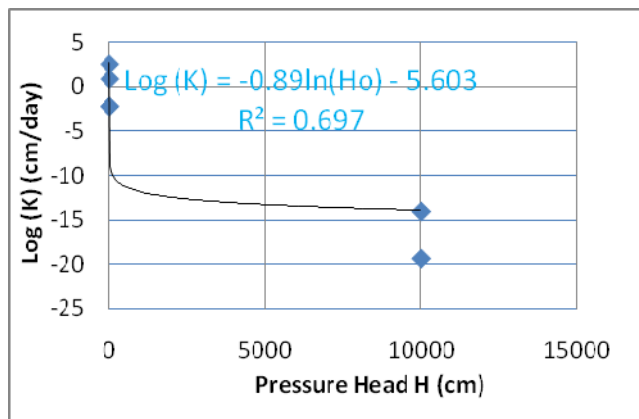


Figure 6. Relationship between Hydraulic conductivity (K) and Pressure head (H) of two layered soil computed with fitting line

The fitting curve line equation derived from Figure 5. and Figure 6. was proposed as a new equation to analyze the hydraulic conductivity (K) of water infiltration ponded condition in two layered soil consist of Manado soil and mix soil sand Bentonite (5%) which is conducted in a vertical soil column with change of water content (θ) and pressure head (H). The equations were given as follow,

$$K(\theta) = 10^{(5.162 * \text{LN}(\theta) + 4.278)} \quad (10)$$

$$K(H) = 10^{(-0.89 \text{ LN}(H) - 5.603)} \quad (11)$$

Where,

$K(\theta)$ is the hydraulic conductivity (K) with change of water content (θ)

$K(H)$ is the hydraulic conductivity (K) with change of pressure head (H)

Equation 10. And 11 were proposed as a new method to analyze the hydraulic conductivity (K) of water infiltration into two layered soil consist of Manado soil (loamy sand) and sand Bentonite (5%) in 1cm x 100 cm vertical soil column.

The effect of change in water content (θ) and pressured head (H) of ponded water infiltration into two layered soil consist of Manado soil (loami sand) and sand Bentonite (5%) mix soil in Figure 3. and Figure 4. shown that sand Bentonite (5%) mix soil more absorb water compare than Manado soil (loamy sand) when the water content and pressure head (H) changed . It was the reason why Bentonite was generally used to increase the mechanical properties of soft soil to solve the geotechnical engineering problems.

CONCLUSION

Two dimensional of ponded water infiltration in two layered soil consist of Manado soil and sand bentonite (5%) soil was analyzed with Hydrus 2D/3D software.

A method (fitting curve line) was proposed to analyzed two dimension of the hydraulic conductivity (K) of water infiltration into two layered soil consist of Manado soil and mix soil sand Bentonite (5%) in a vertical soil column.

Further research is needed to use sand-bentonite mix soil with different composition, soil type with different soil layered and experiment in the laboratory to verify the proposed concept.

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