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Simulation of Sub-Drains Performance Using Visual MODFLOW for Slope Water Seepage Problem

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Abstract. Numerical simulation technique was used for investigating water seepage problem at the Botanic Park Kuala Lumpur. A proposed sub-drains installation in problematic site location was simulated using Modular Three-Dimensional Finite Difference Groundwater Flow (MODFLOW) software. The results of simulation heads during transient condition showed that heads in between 43 m (water seepage occurred at level 2) until 45 m (water seepage occurred at level 4) which heads measurement are referred to mean sea level. However, elevations measurements for level 2 showed the values between 41 to 42 m from mean sea level and elevations for level 4 between 42 to 45 m from mean sea level. These results indicated an increase in heads for level 2 and level 4 between 1 to 2 m when compared to elevations slope at the level 2 and level 4. The head increases surpass the elevation level of the slope area that causing water seepage at level 2 and level 4. In order to overcome this problems, the heads level need to be decrease to 1 until 2 m by using two options of sub-drain dimension size. Sub-drain with the dimension of 0.0750 m (diameter), 0.10 m (length) and using 4.90 m spacing was the best method to use as it was able to decrease the heads to the required levels of 1 to 2 m.

Keywords: Numerical simulation, seepage, modflow.

1. Introduction

Occurrence of water seepage on slope face might be caused by presence of high pore water pressure in subsurface soil strata. Measurements of high pore water pressure always related with several times of heads observation on site that required a lots of number piezometers installation. This works involved time consuming, expensive cost and limited data coverage. Those limitations have created some gap of methods selection which be able to fulfill several considerations that related to cost, time and results quality [1, 2, 3].

Thus, in order to overcome those limitations mentioned, numerical simulation technique was used for investigating groundwater seepage occurs at Botanic Park of Kuala Lumpur. Furthermore, the sub-drain remediation technique approach for resolving a groundwater seepage problem by using simulation technique was also presented.



2. Method and Methodology

2.1 Site description and conceptual numerical model

The study conducted to understand groundwater seepage occurrence at Panggung Anniversary slope area as shown in Fig 1 and Fig 2. The conceptual model consists of a graphic representation of the groundwater flow systems, usually in the form of a block diagram or a cross section [4]. Conceptual model was developed with few assumptions on the aquitard (sandy silt) layers and hydraulic properties. The model boundary condition was extended to the north and south of the Panggung Anniversary location (Fig. 3). Boundary condition for numerical simulation in the north and south area were bounded with constant head boundary. The model was adjusted based on the measured water levels in the study area. Based on that data [5], the aquitard layer is generally formed by a medium to coarse grained SAND with dominant SILT material. The thickness of aquitard ranging from 13 to 25 m and assumed as unconfined layer, while at the bottom is the bedrock which consists of inter-bedded shale and sandstone that can be encountered at depths ranging from 13.0 to 25.0 m. Hydraulic conductivity in this study area ranging from 1.48×10^{-7} to 3.50×10^{-8} cm/sec with an average of 9.25×10^{-8} cm/sec.



Figure 1. Study area and boreholes locations.

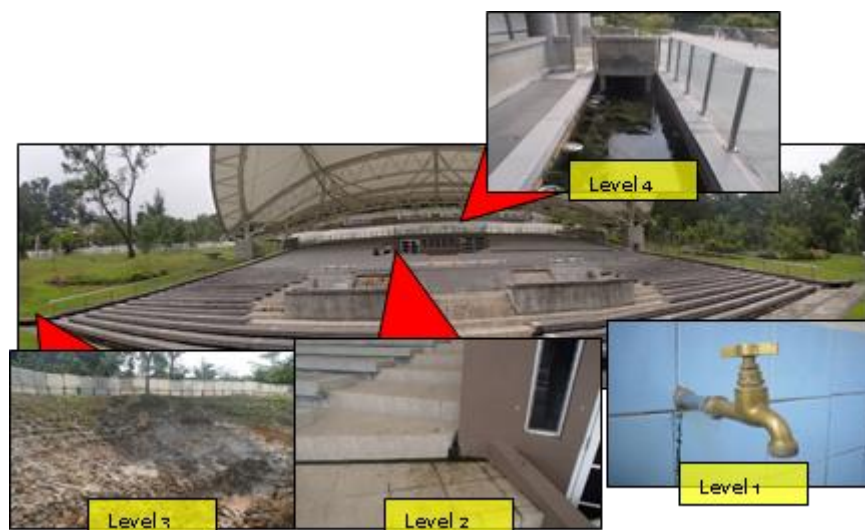


Figure 2. Location of groundwater seepage occurrence at Panggung Anniversary site.

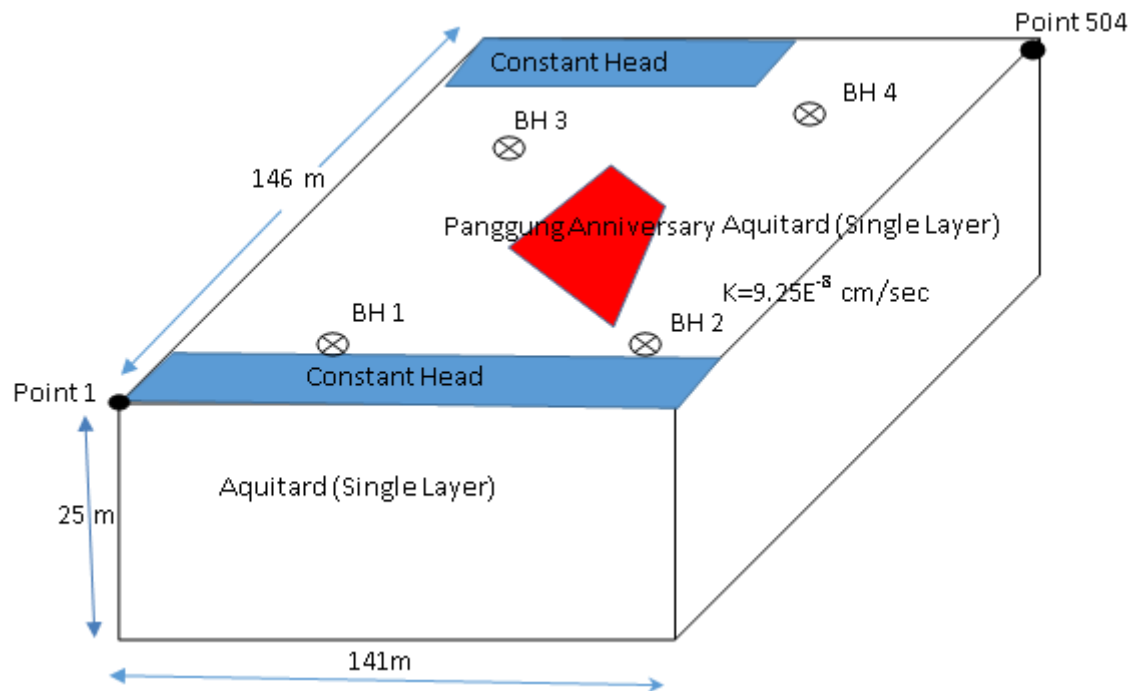


Figure 3. Conceptual model of numerical modelling at Panggung Anniversary site.

2.1 Numerical model setup

Three-dimensional representation of the site was created in Visual MODFLOW. The development of input files was compiled using Visual MODFLOW® (Version 2003.3.1.0.85), a commonly used data preprocessor to accelerate and facilitate the development of the MODFLOW model. This model was created as a 141 m x 147 m area in the x and y directions (east–west and north–south directions, respectively) (Fig. 4). Topography model (the first layer) was imported from elevation data for the wells (BH1–BH4) and surface elevations of the site generated by the digital elevation model and by field survey with the use of theodolite (Fig. 5). Relative elevations of water level monitoring points were determined using a total station theodolite. The water table in the model was referred to indicate sea level (rectified skew orthomorphic). This configuration allowed the placement of the piezometer screens in the model immediately at the terminated borehole depth.

2.3 Model parameters

Hydraulic conductivities of model layer was estimated from the analysed data of permeability tests from BH2 and BH3. Single layer model was assumed to have homogeneous hydraulic properties because the data were not enough to determine heterogeneity layer in this area. Model parameters data such as specific yields (Sy), specific storage (Ss), total porosity and effective porosity values were estimated from data interpreted by previous study (Table 1). A value between 5% and 20% of annual precipitation was recommended as an estimate of recharge when data were unavailable [6]. Hence, recharge was set equal to 10% of the average annual precipitation after the revision throughout model calibration and validation processes. Recharge parameter of surface water into groundwater system was estimated by 10% of total annual rainfall at open area [6]. Meanwhile, zero value of recharge parameter was imposed in closed area of Panggung Anniversary. Evapotranspiration values was estimated using 1.44 times by total annual transpiration at open area. Meanwhile, zero value of evapotranspiration was imposed in closed area of Panggung Anniversary [6].

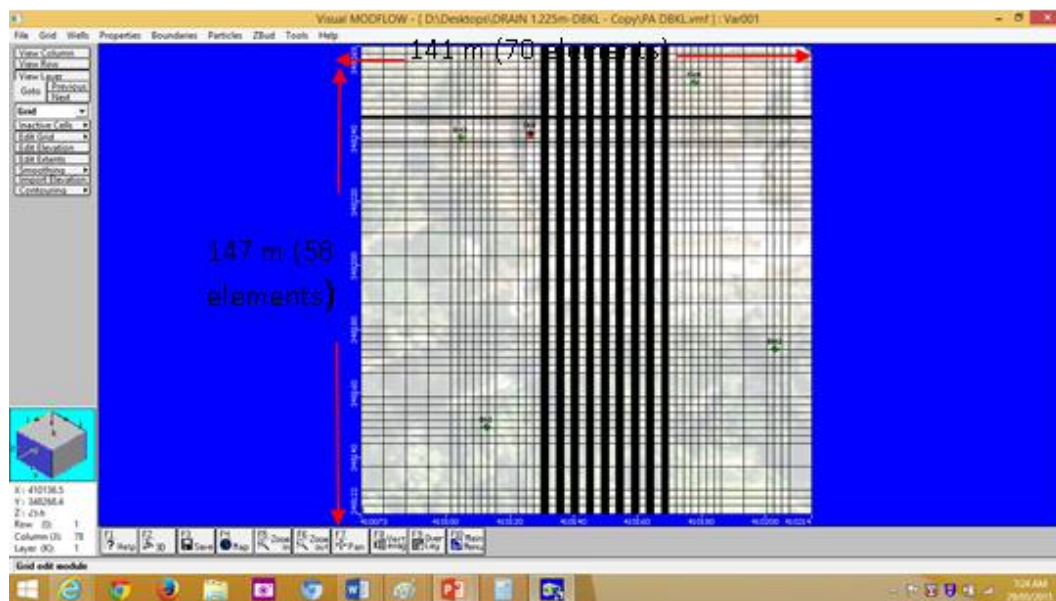


Figure 4. Grid mesh refine and area dimensional.



Figure 5. Surface elevation and boundary of study area.

2.4 Boundary Condition

Constant head boundaries were assigned for the northern and southern edges of the modelled area which are bounded by groundwater head of BH1-BH2 (south) and BH3-BH4 (north). The heads in the model was referred at mean sea level datum. This depth was on average 5 m below the ground surface. The highest heads located at the south area with an average head level of 48 m referred to mean sea level meanwhile the lowest heads located at the south area with an average 38 m referred to mean sea level. The model setup for the remediation technique were applied Drain, Wall and Pumping well Package where are contained in Visual MODFLOW software.

Table 1. Input parameters for the model and simulation strategies for this study.

Parameters	Value
K_x (cm/sec)	9.25e-8 (average value from permeability test average conducted at BH2 and BH3)
K_y (cm/sec)	9.25e-8 (average value from permeability test average conducted at BH2 and BH3)
K_z (cm/sec)	1e-9 [7]
S_s	1e-5 [8]
S_y	0.8 [8]
Total Porosity	0.3 [9]
Effective Porosity	0.15 [9]
Recharge (mm/year)	220 (10% of Annual Rainfall) and 0 at Panggung Anniversary [6]
Evapotranspiration (mm/year)	500 and 0 at Panggung Anniversary [6]
Conductance (m^2/day)	0.00094 – 0.00562

2.5 Transient groundwater flow simulation and calibration

The equation for groundwater flow through the porous media used in the model can be written as a partial differential equation:

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) = S_s \frac{\partial h}{\partial t} - W \quad (1)$$

where K_x , K_y , and K_z are the hydraulic conductivities in the three orthogonal directions (m/s or ft/day), h is the head that drives the flow or the saturated thickness of the aquifer (m or ft), W is the volumetric flux per unit volume and represents the source/sink term for water or withdrawal (m^3/s or ft^3/day), S_s is the specific storage capacity of the porous medium (dimensionless), and t is the time (s or day). When the water withdraws, $-W = R$, where R is a general sink/source term, it is defined to be intrinsically positive to represent recharge (defines the volume of inflow to the system per unit volume of aquifer per unit of time ($ft^3/ft^3/day$ or $m^3/m^3/s$)). The Visual MODFLOW model was run at transient state then calibrated to hydraulic heads recorded on a weekly basis from 16 April 2015 to 7 May 2015 at four standpipes (BH1-BH4) for calibration. For each transient model run, an analysis of the observed versus computed water levels was conducted to determine the accuracy of the simulation.

3. Result and discussion

3.1 Calibration results for groundwater flow simulation

The assessment of the model fit was quantified by the simulations, computed as the difference between the simulated and the observed hydraulic heads. For this model, the estimated average of mean absolute error (MAE) is 0.5 m, the root mean square (RMS) is 1.2 m, and the normalized root mean square error (NRMS) is 12%, which indicate a well calibrated model. Overall, the calibrated model is able to simulate water levels and water level fluctuations sufficiently to evaluate the options of remediation approach on groundwater seepage problem.

3.2 Sub-Drain

Sub-drain was proposed to overcome the water seepage problem at levels 2 and 4. Two options on the sub-drain dimensional design were suggested with taken consideration of materials is easy acquired in market.

Option 1:- 0.0750 m (diameter), 0.10 m (length), 4.90m (spacing)

Option 2:- 0.0375 m (diameter), 0.10 m (length), 4.90m (spacing)

Sub-drain using option 1 showed heads result between 41 and 44 m at level 2 and 4 (Fig. 6) respectively. Drawdown that is the difference in the head between the initial head (without sub-drain) and the head with sub-drain (option 1) showed difference of 1 – 2 m. Meanwhile for option 2, simulated head results showed heads between 42 m at level 2 until 45 m at level 4 (Fig. 7). Drawdown showed difference of 0 - 1 m for option 2 and also indicated that the drawdown was smaller compared to option 1. It was suggested that option 1 with the use of sub-drain of 0.0750 m (diameter), 0.10 m (length) and using 4.90 m spacing can be use in the remediation of the water seepage. This option can reduced the heads in optimal values to prevent settlement of the stage structure.

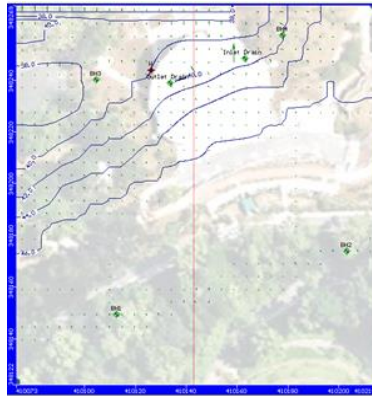


Figure 6. Option 1 (Plan View).

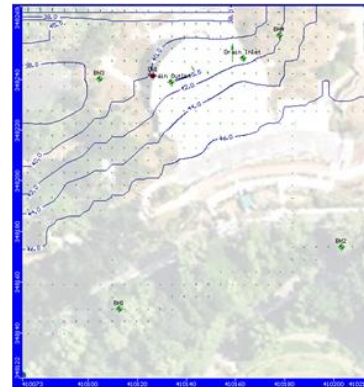


Figure 7. Option 2 (Plan View).

4. Conclusion

The results of the analysis using numerical simulation groundwater flow (Visual MODFLOW), has succeeded in determining the cause of water seepage problem in the study area. Water seepage occurrence at Panggung Anniversary was caused by the elevated groundwater heads compared to the elevation levels of the area. In order to overcome the water seepage occurrence caused by the increase of heads level, the reduction of the head levels between 1 – 2 m need to be done. The usage of the sub-drain with dimensional design of 0.0750 m (diameter), 0.10 m (length) and using 4.90 m spacing was able to reduce about 1 – 2 m of the heads level and is the best option of remediation to be considered. The usage of dimensional design remediation with sub-drain is the safest method to be use to prevent any structure settlement from occurring.

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