APPLICATION OF METHODS FOR EVALUATING AQUIFER-SYSTEM PARAMETERS: CASE OF SOIL IN MY THUAN BRIDGE, VINH LONG PROVINCE

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Abstract

Determining hydrogeological parameters is one of the important tasks of groundwater dynamics, in which the storage coefficient is an indispensable parameter to predict subsidence. Compaction and water-level data were assumed to collect data from a borehole extensometer recorded and groundwater pumping test in My Thuan bridge, Vinh Long province to estimate elastic and inelastic specific coefficient (S) in aquifer-system. The purpose of this study is to estimated and compared specific storage by three methods such as Theis's method, Riley's method and Galloway's study in My Thuan bridge site, Vinh Long province. The final value of the storage coefficient is 0.00052. The results of this study also are the basis for calculating settlement and the impact that mining may have on regional groundwater flow systems.

Keywords: *specific coefficient, aquifer-system, compaction, elastic, inelastic, groundwater.*

1. Introduction

Nowadays, the Mekong Delta is seriously affected by climate change, which has effect agriculture, human health, food security and water resources, especially is the groundwater may cause compaction and subsidence. This large demand for groundwater has placed considerable stress on the aquifer-system.

Compaction and subsidence continue in both areas and may cause damage to manmade structures as well as reducing long-term yield to wells. The simulations were most sensitive to reduction of initial preconsolidation stress and least sensitive to changes in aquifer specific storage (Hanson, 1988). Compaction is used to describe the decrease in thickness of sediments as a result of an increase in the vertical compressive stress. A one-dimensional mathematical model that calculates idealized aquifer-system compaction and expansion has been applied to observed water-level fluctuations and to the resulting observed transient compaction-expansion behavior of a total thickness interval at one site in the San Joaquin Valley (Helm, 1976). This field method of aquitard parameter evaluation has advantages over laboratory methods.

The storage coefficients (S) of the aquifer-system is permanently reduced when lowering groundwater. The term "storage coefficient" is used to describe water that is released from or take into storage (Alex, 1989). Specific storage (S_s) is a property of both earth and water that describes how much water is released from storage in a pressure (confined) aquifer for each meter decline in hydraulic head (Anderson, 2018), which is the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head (Lohman, 1988). Specific storage can be estimated by many methods, including analysis of geotechnical. The typical storativity of a confined aquifer, which varies with specific storage and aquifer storage and aquifer thickness, ranges from 5×10^{-5} to 5×10^{-3} (Todd, 1988). The specific storage is useful for predicting a lower limit for the magnitude of subsidence.

Riley (1969) demonstrated that estimated aquitard elastic and inelastic skeletal storage coefficients could be graphically calculated from stress-strain plots assuming constant total stress was acting on the aquifer-system. If additional geologic data on the number and thickness of aquitards are available, the specific storage, or compressibility, can be estimated. On the other hand, in the aquitards and aquicludes which have low hydraulic conductivity and high specific storage, the vertical escape of water and adjustment of pore pressure is slow and time-dependent (Poland, 1969).

If the initial hydraulic head (starting water level) is above the initial critical head, the elastic-storage value is used until the hydraulic head falls below the critical head. When this happens, the elastic-storage value changes to an inelastic-storage value, associated with inelastic compaction, at the beginning of the next time step. The inelastic-storage value is used until the hydraulic head begins to recover; then the inelastic-storage value returns to the elastic-storage value. Elastic storage is a result of the expansion of water and the compression of sediments because of change in fluid pressure. Change in elastic storage is computed as the product of the elastic specific storage, the thickness of the confined aquifer, the aquifer area, and the decline in head (Alex, 1989). The amount of water that can be stored in the aquifer system during the recovery period by elastic storage is much less than the amount released by inelastic compaction (Poland and Davis, 1969).

Therefore, the effective stress increase in the confined aquifers is equal to the decrease in fluid pressure. The aquifers respond essentially as elastic bodies. Hence the compaction in these is immediate and is chiefly recoverable if fluid pressure is restored, but usually is very small (Poland, 1969).

When a well is pumped or otherwise discharges, water levels in its neighborhood are lowered. Unless this lowering occurs instantaneously it represents saturated sediments if the aquifer due to lowered pressure if the aquifer is artesian (Theis, 1952).

The purpose of this study is to estimated and compared the elastic and inelastic specific storage in aquifer-system in the study area by many methods (Theis's method, Riley's method and Galloway's study) by compaction values and groundwater pumping values. Borehole extensometer records and ground-water hydrographs from piezometers are used to construct plots of effective stress and deformation. Elastic and inelastic specific storage are also estimated from the plots of effective stress and deformation. Limited research to calculate specific coefficient for aquifer-system compresses elastically.

2. Analysis Methods

2.1 Theis's method (1935)

Theis (1935) developed an analytical solution for flow to a fully penetrating line sink discharging at a constant rate in a homogeneous, isotropic and nonlinearly confined aquifer of infinite extent is as follows:

$$S(r,t) = \frac{Q}{4\pi T}\int_u^{\infty}\frac{e^{-u}}{u}du \quad (1)$$

$$u = \frac{r^2 S}{4Tt} \quad (2)$$

Groundwater hydrologists commonly refer to the integral in (1) as the Theis well function, abbreviated as w(u). For the specific definition of u given above, the integral is known as the *well function*, *W(u)* and can be represented by an infinite Taylor series of the following form:

$$S = \frac{Q}{4\pi T}w(u) \quad (3)$$

Using this function, the equation becomes:

$$w(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} + ... \quad (4)$$

(where: Q is pumping rate (m^3/day), r is radial distance from pumping well to observation well (m), s is drawdown (m), S is storativity (dimensionless), t is elapsed time since start of pumping (min or hour), T is transmissivity (m^2/day), w(u) is the Theis well function for nonleaky confined aquifers (dimensionless)).

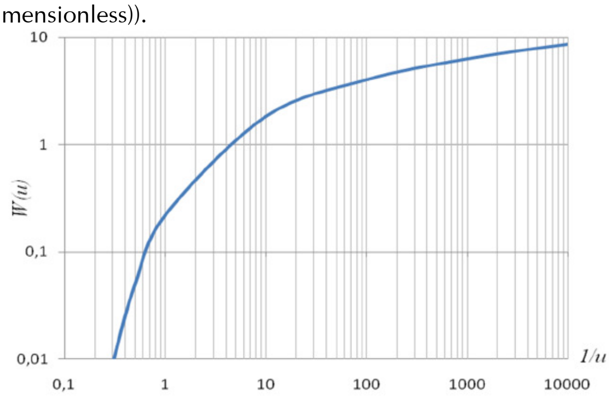

Figure 1. Theis standard curve for pressure aquifer (Phat et al., 2014).

The line on a log-log plot with W(u) along the Y-axis and 1/u along the X-axis is commonly called the Theis curve. The field measurements are plotted as t or t/r^2 along the X-axis and s along the Y-axis. The data analysis is done by matching the line drawn through the plotted observed data to the Theis curve.

2.2 Riley's method (1969)

The time-varying stress-strain relation, measured in terms of drawdown and recovery in the aquifers and the vertical component of compression and expansion of the aquifer system, can provide estimates of the inelastic compressibility of the aquitards and the elastic compressibility of the aquifer system. For a specialled stress increase, the compressibility, β_ω, of the water, and the thickness, b', of the aquitard. The impedance is determined by the vertical permeability, K', and thickness of the aquitard. Thus, the required time, t, is a function of the time constant, τ, where

$$\tau = \frac{S'_s(b'/2)^2}{K'} \quad (4)$$

and where S'_s is the specific storage of the aquitard, defined as:

$$S'_s = S'_{sk} + S_{s\omega} \quad (5)$$

In which

$$S'_{sk} = \frac{\Delta b'}{b'\Delta h_a} \quad (5a)$$

and

$$S_{s\omega} = n\beta_\omega\gamma_\omega \quad (5b)$$

S'_{sk} is the component of specific storage due to compressibility of the aquitard, $S_{s\omega}$, is the component due to the compressibility of water, h_a is the average head in the aquitard, n is the porosity, and γ_ω is the unit weight of water. For consolidating aquitards $S'_{sk} >>> S_{sw}$.

2.3 Galloway's study (1998)

The elastic and inelastic sketelal compressibilities, α'_k, of the aquitards are expressed om term of the skeletal specific storeges, S'_{sk}:

$$\begin{aligned} S'_{sk} &= S'_{ske} = \alpha'_{ke}\rho g, \quad \sigma_e < \sigma_{e(\max)}, \\ S'_{sk} &= S'_{skv} = \alpha'_{kv}\rho g, \quad \sigma_e > \sigma_{e(\max)}, \end{aligned} \quad (6)$$

where the primes signify aquitard properties, subscripts e and v refer to the elastic and virgin (inelastic) properties, ρ is fluid density and g is gravitational acceleration, maximum effective stress, $\sigma_{e(\max)}$; effective stress is σ_e the aquitard skeletal storage coefficient S'_k:

$$\begin{aligned} S'_k &= S'_{ke} = S'_{ske}(\sum b'), \quad \sigma_e < \sigma_{e(\max)}, \\ S'_k &= S'_{kv} = S'_{skv}(\sum b'), \quad \sigma_e > \sigma_{e(\max)}, \end{aligned} \quad (7)$$

A similar set of equations, one of the coarse-grained aquifers and one for the pore water, relates the compressibility of the aquifer system storage attributed to the pore water (S_w):

$$\begin{aligned} S_k &= S_{sk}(\sum b') \approx \alpha_{ke}\rho g(\sum b) \\ S_w &= \beta_w \rho g\left[n\left(\sum b\right) + n'\left(\sum b'\right)\right] \end{aligned} \quad (8)$$

where $\sum b$ is the aggregate thickness of the aquifers; n and n′ are the porosities of the aquifers and aquitards.

The aquifer-system storage coefficient S*:

$$S^*=S'_k+S_k+S_w \quad (9)$$

3. Considered cases

Figure 2 presented generalized soil profile. The soil profile at the bridge site can be summarized as follow: (i) First "Clay" Layer, (ii) First Sand Layer, (iii) Second Clay Layer, (iv) Second Sand Layer, (v) Third Clay Layer, (vi) Third Sand Layer.

Based on the results of the field and laboratory test results, the geological model shown in Figure 3 was formulated for the site, for the purpose of providing geotechnical parameters for the design of the bridge foundation elements, and of the approach embankment.

The study was carried out at a borehole in My Thuan bridge, which had 4 layers in Figure 4, the total thickness of the aquifer-system is 130m. The confined middle aquifers, along with the deep aquitard (Figure 2), were considered their own multi-layered aquifer-system. Aquifer-system primarily alternat consists of thick clay with thin sand layers. The aggregate thickness of aquitard is 72m and the aggregate thickness of aquifer is 58m.

The aquifer and aquitard properties may extensometer data or may be based on estimated from geologic considerations in the paper. The simulation, the water-level records were presented in table 1, data on number and thickness of compressible aquitards in the compacting aquifer system, which references from data in Poland's study in 1972.

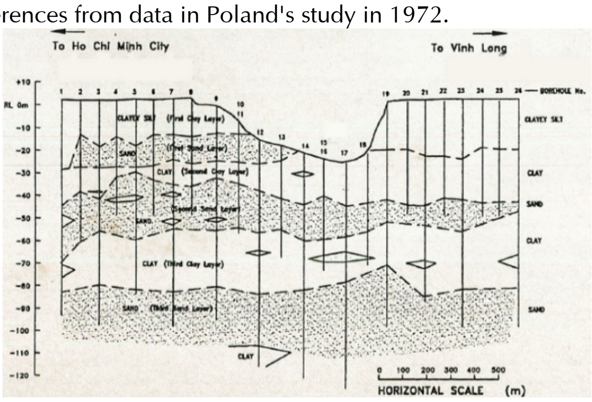

Figure 2. Soil profile in My Thuan bridge, Vinh Long province.

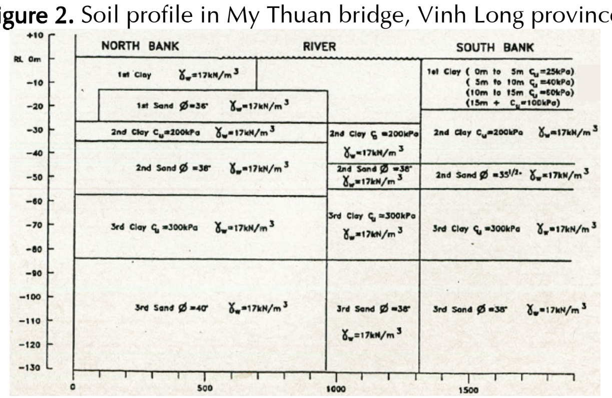

Figure 3. Geotechnical model in My Thuan bridge, Vinh Long province.

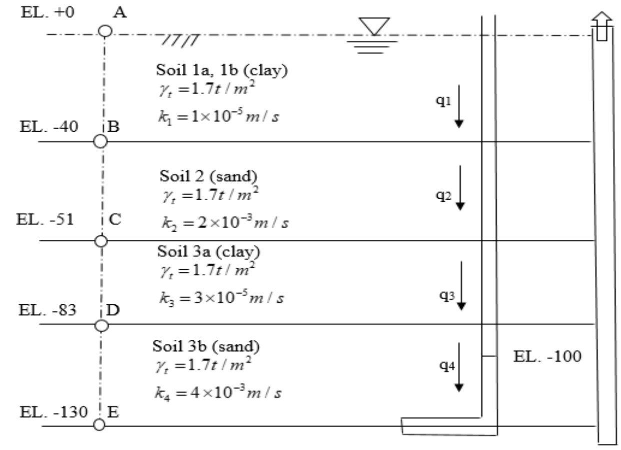

Figure 4. Aquifer-system in My Thuan bridge, Vinh Long province.

Assuming for document borehole pumping experiment which presents in table 3. Based on the research of Phat et al. and compaction values on Erban et al. present data of pumping test in the field by the method of groundwater (GW) pumping test, which shows in table 4.

Table 1. Annual compaction rates at compaction-measuring sites (Values were simulated from annual compaction rates at compaction-measuring sites, San Joaquin Valley (Poland, 1972)).

Well number		1	2
Anchor depth when installed (m)		-100.0	-100.6
Depth interval (m)		100.0	100.6
Annual compaction values	2006	0.029	0.030
	2007	0.030	0.035
	2008	0.033	0.040
	2009	0.036	0.039
	2010	0.032	0.036
Total measured compaction (m)		0.160	0.172

Table 2. Geological parameters of My Thuan Bridge.

Aggregate thickness (m)	Aquifer (b)	72
	Aquitard (b′)	58
	Total monitored (b*)	130
The change in compaction (Δb) (m)		0.012
The change effective stress (Δh) (kN/m^2)		6
The change in groundwater table (Δa) (m)		0.6
Diameter of pile (d) (m)		3.50
Volume (m^3)		0.005
Compressibility (cm^{2}kg^{-1}) (Freeze et al. 1979)	Clay (α'_{ke})	10^{-8} to 10^{-6}
	Sand (α_{ke})	10^{-9} to 10^{-7}
Compressibility of water (β_w) (cm^{2}kg^{-1}) (Riley, 1969)		4.7 x 10^{-5}
Gravitational acceleration g (m^3/s)		9.81
Density of water (ρ) (kg/m^3)		1
Unit weight of water (γ_w) (kN/m^3)		1
Porosity (n)		0.53

Table 3. Document of experimental borehole pumping.

Name of well	Deep of well	Thickness of aquifer b (m)	Distance from pump well to observation well r (m)	The rate of water flow Q (m^3/h)
1	130	58	86	20

Table 4. Pumping test data for borehole in My Thuan bridge.

No.	Time (Min)	Drawdown of the water table (cm)
1	0	0
2	5	1.6
3	10	2.9
4	15	4.2
5	20	4.4
6	25	4.6
7	30	4.8
8	35	5.0
9	40	5.2
10	45	5.4
11	50	5.6
12	55	5.8
13	60	5.9
14	65	6.2
15	70	6.5
16	75	7.3
17	80	7.5
18	85	8.7
19	90	9.3
20	95	9.5

4. Results and discussions

4.1 Results of Theis's method

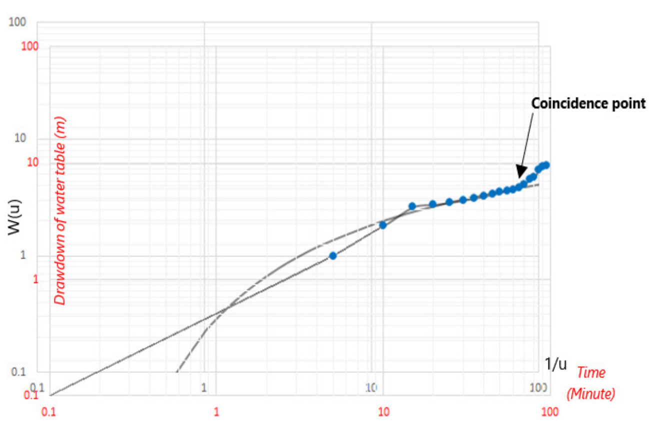

Figure 5. Coincidence of s ~ t curve with Theis standard curve.

Table 5. Values of the hydro-geological parameters of Theis's method.

Con.	1/u	W(u)	s cm	t min	T m^2h^{-1} $\frac{Q}{4\pi s}W(u)$	K mh^{-1} $\frac{T}{b}$	S $\frac{4uTt}{r^2}$
Values	85	2.3	5.2	70	70.43	1.21	5.19x10^{-4}

From the pumping test data for borehole in My Thuan bridge. In Table 4, graphing the plot of the relationship between the water level of drawdown (s) and the pumping time (t) on logarit paper.

Put on the relationship curve (s ~ t) was drawn and the Theis standard curve (the same scale) on each other and select the coincidence point as presented in Figure 5.

Figure 5 shows the point of coincidence, at this point has values: (1/u) = 85; W(u) = 2.3; s = 5.2cm and t = 70min. From here to calculate the hydro-geological parameters, the results present in table 5. The storage coefficient in this method is 5.19 x 10^{-4}.

4.2 Results of Riley's method

Table 6. Results for specific storage parameters of Riley's method.

Component due to skeletal compressibility					
Average specific storage			Storage coefficients		
Aquifers S_{ske} (m^{-1})	Aquitards S'_{ske} (m^{-1})	Aquifer-system S^*_{ske}(m^{-1})	Aquifers S_{ke}	Aquitards S'_{ke}	Aquifer-system S^*_{ke}
2.89x10^{-6}	4.51x 10^{-7}	3.34 x 10^{-6}	1.67x10^{-4}	3.25 x 10^{-5}	2 x 10^{-3}
Total skeletal plus water compressibility storage					
Average specific storage			Storage coefficients		
Aquifers S_s (m^{-1})	Aquitards S'_s (m^{-1})	Aquifer-system S^* (m^{-1})	Aquifers S	Aquitards S'	Aquifer-system S*
5.38x10^{-6}	2.94 x 10^{-6}	4.16x10^{-6}	3.12x10^{-4}	2.11 x 10^{-4}	5.24 x 10^{-4}

4.3 Results of Galloway'study

Table 7. Results for specific storage parameters of Galloway's study (Choose: $\alpha'_{ke} = 7.3\times10^{-7}\left(cm^2kg^{-1}\right); \alpha_{ke} = 1.5\times10^{-8}\left(cm^2kg^{-1}\right)$).

Component	Values
$S'_{sk} = S'_{ske} = \alpha'_{ke}\rho g$ (m^{-1})	7.16 x 10^{-6}
$S'_k = S'_{ke} = S'_{ske}b'$	5.16 x 10^{-4}
$S_{ke} = \alpha_{ke}\rho gb$	7.97x 10^{-6}
$S_{ske} = S_{ke}/b$ (m^{-1})	1.37 x 10^{-7}
$S_w = \beta_w\rho g\left[nb + n'b'\right]$	3.18 x 10^{-6}
$S^* = S'_k + S_k + S_w$	5.26 x 10^{-4}

Table 6 presents the result of analyses according to Riley's method. In component due to skeletal compressibility, average specific storage in aquifer-system is 3.34 x 10^{-6}(m^{-1}), storage coefficients in aquifer-system is 2 x 10^{-3}. Total skeletal plus water compressibility storage, average specific storage in aquifer-system is 4.16 x 10^{-6}(m^{-1}), storage coefficient in aquifer-system is 5.24 x 10^{-4}.

Table 7 shows the result of analyses according to Galloway's study. The storage coefficient in aquifer-system is 5.26 x 10^{-4}.

Comparing the results of three methods, the storage coefficient is nearly equal and the value is 5.2 x 10^{-4}.

The component or specific storage coefficient attributable to compressibility of the granular skeleton of sediments determines the magnitude of mechanical deformation resulting from a unit change in head (pore pressure). When the increasing intergranular stress caused by declining pore pressures exceeds the maximum past stress.

5. Conclusions

Compaction and water-level data were assumed to collect data from a borehole extensometer recorded and groundwater pumping test in My Thuan bridge, Vinh Long province, application for methods for evaluating aquifer-system parameters from Theis's method, Riley's method and Galloway's study. The calculation has been used to determine numerous aquitard elastic and inelastic skeletal specific storage values for all types of aquifer-system arrangements. The storage coefficient is one of hydro-geological parameters.

The storage coefficient in aquifer-system in My Thuan bridge by three methods is 5.2 x 10^{-4}. The less compressible the aquitard units are the closer the average inelastic skeletal specific storage will be to the aquitard elastic skeletal specific storage values. The results of this study are also the basis for calculating settlement and the impact that mining may have on regional groundwater flow systems.

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