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Water Infiltration Characteristics for Artificial Lake in Bahr Al-Najaf

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ABSTRACT

Al-Najaf is one of the important cities in Iraq due to its high spiritual and religious reputation that attracts Moslems from different parts of the world to visit the holy shrine of Al-Imam Ali (peace be upon him). The city of Al-Najaf and particularly Bahr Al-Najaf area, is expecting a number of large scale construction activities, among these development activities are the planning of a new tourist city called Sayf Thulfiqar city. Sayf Thulfiqar city is planned to be the largest tourist city in Iraq. The area of the proposed tourist city is about 63 hectares, consists of an artificial lake 1000m long surrounded by twelve towers and a number of small dwellings. This lake is considered as a big challenge in planning, construction, and sustainability. The challenging points primarily are the sources of water required to fill the lake, infiltration characteristics of the soil at site, weather conditions, etc.

The present paper focuses on investigating the rate of water infiltration through the base and side walls of a pit with dimensions 3m by 3m and 0.5m in depth excavated and filled with water in the location of artificial lake. The process of filling was repeated several times with full observation and continuous field measurements. The results revealed some useful characteristics and correlations regarding the infiltration of water of artificial lake in Bahr Al-Najaf.

Keywords: Infiltration, Bahr Al-Najaf, Al-Najaf, Infiltration rate, Artificial Lake, Sayf Thulfiqar

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خصائص ترشح المياه لبحيرة صناعية مقترحة في بحر النجف

الخلاصة

مدينة النجف هي واحدة من المدن المهمة في العراق نظرا لسمعتها الروحية والدينية العالية التي تجذب المسلمين من مختلف أنحاء العالم لزيارة مرقد الإمام علي (عليه السلام) .مدينة النجف وخاصة منطقة بحر النجف، تتوقع عدد من المشاريع الكبيرة، ومن بين هذه المشاريع الإنمائية هي التخطيط لمدينة سياحية جديدة تسمى "مدينة سيف ذوالفقار" .ومن المقرر ان تكون هذه أكبر مدينة سياحية في العراق .وتبلغ مساحة المدينة السياحية المقترحة حوالي 63هكتار، تتوسط المدينة بحيرة صناعية بطول 1000 متر تحيطها اثنى عشر برجا وعدد من المساكن الصغيرة .وتعتبر هذه البحيرة تحديا كبيرا في عمليات التخطيط والتصميم والتنفيذ والاستدامة . وفي المقام الأول، مصادر المياه اللازمة لملء البحيرة، وخصائص ترشح المياه من التربة في الموقع، الأحوال الجوية، ... الخ.

يركز هذا البحث على ايجاد معدل ترشح المياه من خلال قاعدة والجوانب حفرة ذات أبعاد 3*3*0.5 متر ومملوءة بالماء في موقع البحيرة الصناعية . تكررت عملية ملء الحفرة عدة مرات مع مراقبة كاملة للترشح وقياسات ميدانية المستمرة .كشفت نتائج البحث بعض الخصائص المفيدة والعلاقات الرياضية فيما يتعلق ترشح المياه.

INTRODUCTION

Artificial lakes are constructed for many purposes mainly for industrial or agricultural uses, however artificial lakes are sometimes used for hydro-electric power generation, domestic water supply, aesthetic or recreational purposes[1].

Construction of artificial lakes requires special requirements that keep water retained and not soak through the ground. Natural layers of clay are compressed to prevent water loss, sometimes synthetic liner will have to be added to create a blanket that control any seepage. Some lakes require additional filtration and temperature control technologies. Final landscaping around the lake provides a natural appearance as if the lake had been there for many years [2].

Water entry into the soil by infiltration is among the most important of soil hydrological processes, it controls the partitioning between runoff and soil water storage. The infiltration rate is a time-varying quantity that is highly dependent on soil properties that are generally highly variable in space, both in the vertical and horizontal directions of the hydrologic basin. The infiltration rate of a soil depends on factors that are constant, such as the soil texture. It also depends on factors that vary, such as the soil moisture content and soil structure [3].

Infiltration measurements are usually made to determine the infiltration rate, which is significant in irrigation and hydrologic studies. This rate decreases with time and tends to approach a constant value. All the information can be shown on a graph of cumulative infiltration versus time. An ideal infiltration curve, based on theoretical analysis, is illustrated in Figure (1), demonstrating the cumulative infiltration versus time. Figure (2) shows the ideal infiltration rate with time [4, 5].

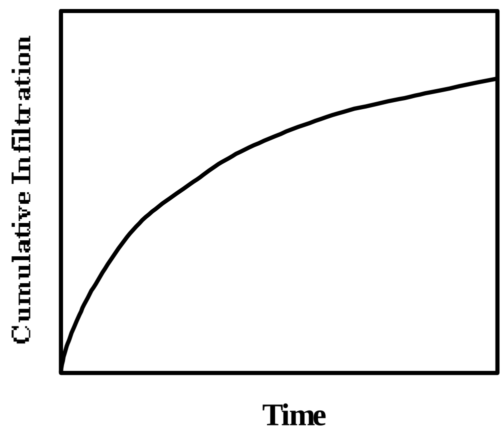


Figure (1) Ideal Infiltration Curve [4, 5].

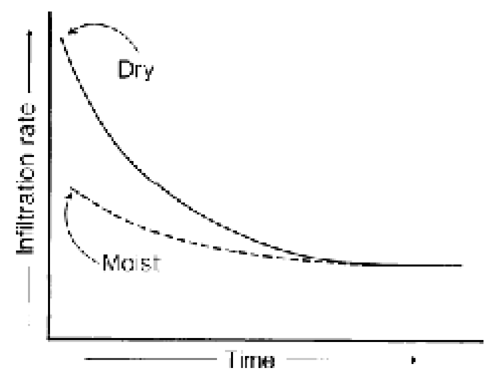


Figure (2) Ideal Infiltration Rate Curve [4, 5].

The artificial lake to be constructed as part of Sayf Thulfiqar city, requires some knowledge about the infiltration of water in Bahr Al Najaf, this was the main objective of the field tests presented in this article.

SITE DESCRIPTION

Sayf Thulfiqar artificial lake and the tourist city is located in Bahr Al-Najaf southern west of Najaf city, about 160 km south of Baghdad city in west of the Euphrates river, near Al-Hawly street and close to the old city. The city consists of several high rise buildings as large hotels and many residential buildings like small dwellings in addition to many other services. The artificial lake is one of the main items in this city. All structures are located on the shore or close to the shore of the artificial lake.

The difference in elevation between the tourist city and highest elevation in Najaf city (Imam Ali Shrine) is about 30m to 45m. The area of the tourist city is about 63 hectares.

The old Najaf city is that the part of Al Najaf city which is near and surrounding the holly shrine of the Al Imam Ali. It consists of small districts (Al Mishraq, Al Emarah, Al Boraq, and Al Howwaish) and the streets between them with total area of about 2 km^2 [4].

The depression of Bahr Al-Najaf extends longitudinally a distance of 40 km from the north-west of the city of Najaf toward the southwest of the city. The width of this depression ranges from 6km to 60km along the Tar of the city.

Field Work

Test Pit Excavation

A test pit was of dimensions 3.0m in length, 3.0m in width, and average depth of 0.5m was excavated to perform the infiltration test, within the boundaries of Sayf Thulfiqar lake. Figure 3 shows the location of infiltration test.

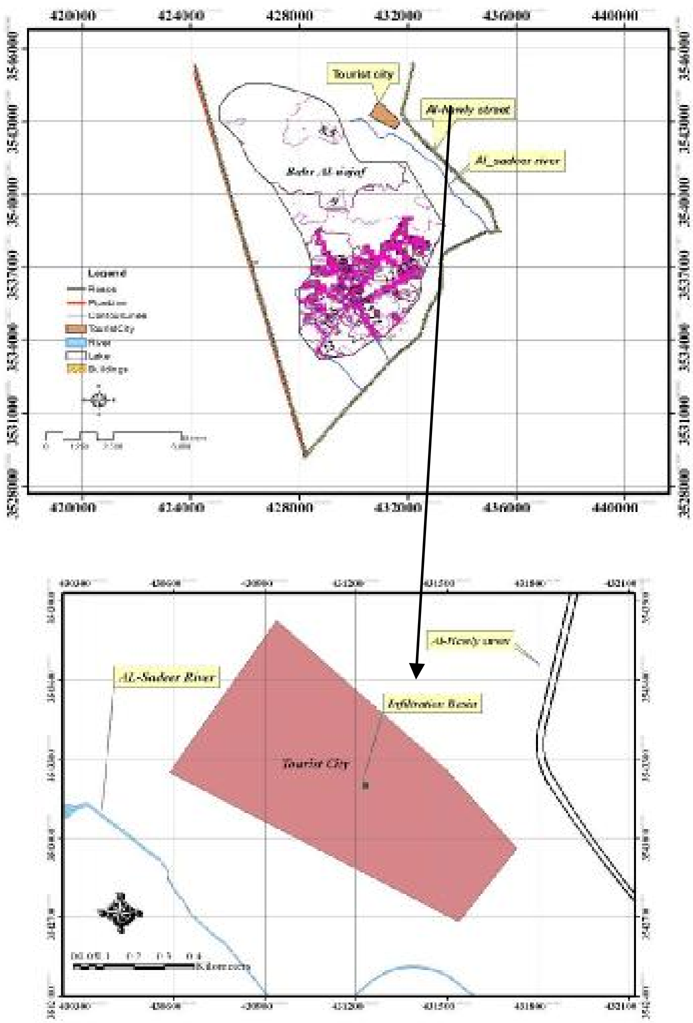


Figure (3) Area of the Investigation [6].

Soil Classification

During the drilling process of infiltration basin, disturbed sample was collected. Figure (4) demonstrates the grain size distribution of the soil sample. The soil consists of 1.02 % gravel, 90.48 % sand, % 8.5 fines. Chemical tests were also performed. Table (1) summarized the results of the soil tests and classification. The tested soil is considered to be slightly gypsies soil according to Barazanji (1973) classification [7].

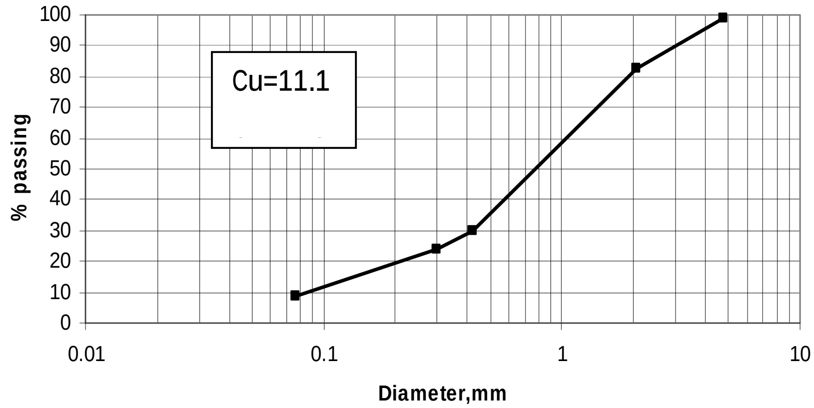


Figure (4) Grain Size Distribution Curve of Soil Sample in Infiltration Basin Location.

Table (1) Summary of Soil Tests.

Soil sample	Water content, %	SO_3, %	Gypsum, %	TSS, ppm	Soil Classification according to USCS	
					Group symbol	Typical names
	14.23	2.56	5.12	565	SW- SC	Well graded- sands, gravelly sands, (little or no fines), Clayey sands, sand-silt mixture.

RESULTS AND DISCUSION

Infiltration Test

After the completion of the excavation, the dimensions of the pit were measured and then the pit was filled with water using 8000 liters water tanker. The flooding process (flooding and infiltration) continued for about four weeks using 4 tankers.

Plate (1) shows the initial and final stages of filling process. The flooding process was divided into four stages. The term "stage" refers to the time from the beginning till the end of the filling process and continues to the end of infiltration of the flooding water.

The process of measuring the infiltration starts immediately after the completion of the filling process, although some of the water infiltrated to the soil during the filling process. The flooding process is divided into four stages and during each stage, the drops in water level in the pit at successive time intervals were reported.

Figure (5) shows the relationship between the cumulative time periods and cumulative drop in water height for the four stages of flooding process. Figure (5a) indicates a gradual nonlinear rate followed by a constant rate till the end of the stage. During this stage, the rate of change of cumulative drop versus cumulative time is high compared to other stages due to the initial dry state of the soil. The other stages, 2, 3, and 4 of infiltration exhibited close linear relationship between the cumulative infiltration and cumulative time, with lower rates compared to the first stage. This situation may be attributed to complex changes occurred in the skeleton of the soil due to the wetting progress. The changes in the degree of saturation due to continuous flooding contribute in dissolution of salts; lose of bonds and rearrangement of soil particles.

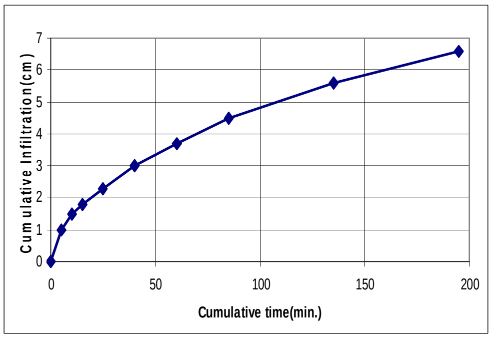
a. During filling stage

b. After filling stage

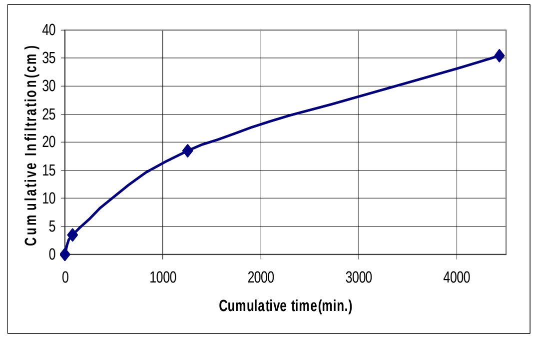
Plate (1) The Filling Process.

Figure (5b) shows the results of infiltration rate of the second stage, where lower initial values were observed as compared with corresponding values of the first stage. Similar to the previous two stages, stage three was performed in four days. It is observed from Figure (5c) that the infiltration of this stage is in close agreement in trend with the last previous cycle of stage 2.

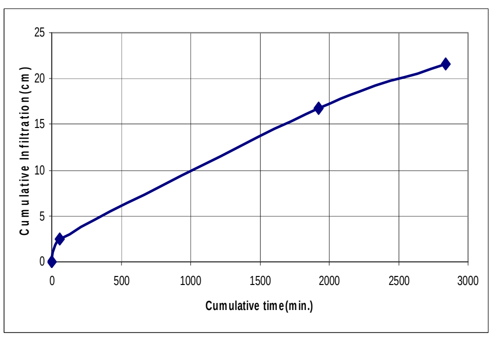
Stage 4 was performed in two days and half. Once again, it is observed from Figure (5d) that the infiltration of this stage is in close agreement in trend with the last cycle of stage 3. This phenomenon is repeated between stages one and two, two and three, and three and four.



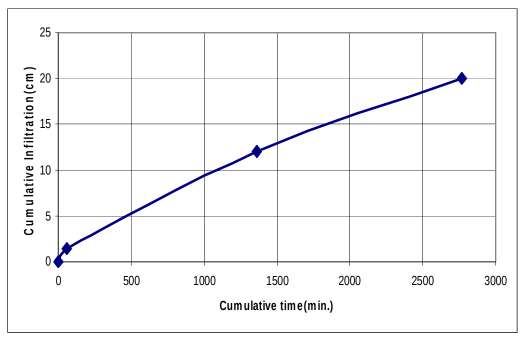
a: First Stage.



b: Second Stage.



c: Third Stage.

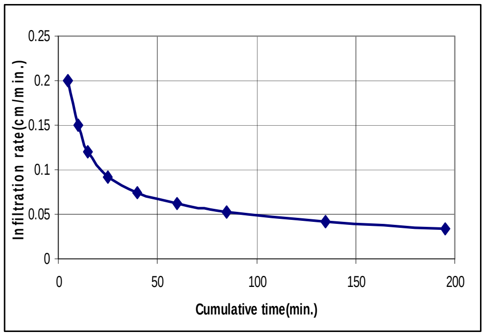


d: Fourth Stage.

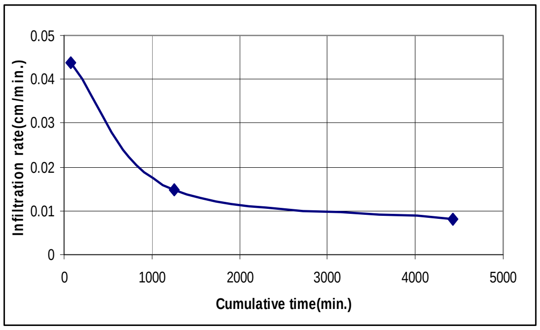
Figure (5) Cumulative Infiltration versus Cumulative Time of the Four Stages.

Figure (6) shows the results of infiltration rate of the four stages. The infiltration rate, defined as the volume of water passing into a unit area of soil per unit time, is calculated for each infiltration stage and plotted versus cumulative time. All the four stages exhibit a decreasing trend of infiltration rate versus cumulative time

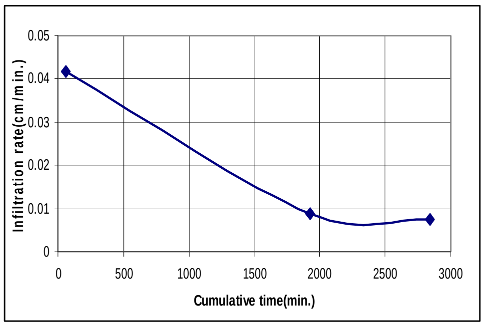
The first stage Figure (6a) exhibited the highest initial rate 0.2 and decreased to 0.04. For the second stage Figure (6b), the initial rate value is 0.045 and gradually decreased to 0.009. Lower initial values were also observed in stages 3 and 4 as compared with corresponding values of the first stage. Such behavior is expected as the gradual advancing of wetting continuous to move with increasing number of stages Figures(6c and 6d).



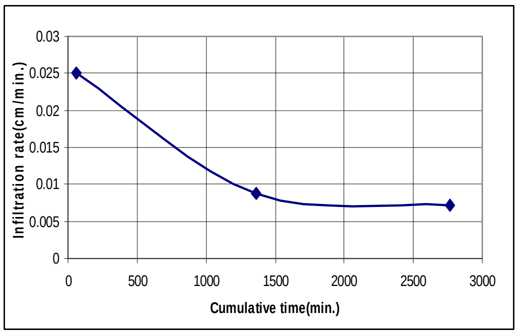
a: First Stage.



b: Second Stage.



c: Third Stage.



d: Fourth Stage.

Figure (6) Results of Infiltration Rate versus Cumulative Time of the Four Stages.

Comparison with available models

Several empirical mathematical models adequately fit many measurements such as [4, 5]:

$$\mathbf{I = a.\ t^{b}} \quad \dots (1)$$

$$\mathbf{I = ct^{1/2} + d} \quad \dots (2)$$

Where I is the cumulative infiltration in cm; t is time in minute; a, c, and d are constants. The constant b is found to be about 0.5 in many measurements of water movement into dry soil where suction forces predominate and gravitational forces are negligible, in wet soils the constant b approaches 1.0.

Mezencev 1957, proposed the following mathematical model to find infiltration rate as follows [8, 9]:

$$I_R=i_f+\alpha.t^{-\beta} \quad \dots (3)$$

Where I_R is the Infiltration rate(L/T); i_f is the final infiltration rate at steady state; α and β are empirical constants,(where $\alpha>0$, $0< \beta <1$).

Cumulative Infiltration Model

Using computer program named "Curve Expert", Eq. 4 relates the cumulative infiltration and cumulative time during the whole time of the four stages of flooding. The equation provided R^2 equal to 0.9947. This is the best fit of the data primarily based on a function demonstrating the relationship in equation 1.

$$I=0.1595.\ t^{0.6743} \quad \dots (4)$$

Where I is the cumulative height of water infiltrates into the soil in cm; and t is the time from the beginning of the infiltration in minute.

The coefficients a and b in equation 1 are equal to 0.1595 and 0.6743 respectively for Sayf Thulfiqar city soil for all five infiltration stages. The coefficient b (0.6743) shows the process of wetting advancing in the soil.

Infiltration Rate Model

In the first stage, the soil is initially dry and so the expected infiltration rate is high then gradually decreases as the soil becomes wet. The results of infiltration rate clearly indicate a clear reduction in the infiltration rate between the initial and final values. The initial rate is high due to the state where the soil is most likely dry in its natural moisture content and once exposed to water it will absorb it rapidly and hence reduce the ability of infiltration. Considering the initial value of stage 1 being equal to 0.2 cm/min. then reduced to 0.0072 cm/min. at the final stage of stage 4. One reason for this reduction is the advance of the water front after each stage of flooding. This advancement of the water front increases the degree of saturation and causes dramatic changes in the skeleton of the soil and ultimately reducing the infiltration rate. Equation 5 relates the infiltration rate and cumulative time during the whole time of the four stages of flooding with R^2 equal to 0.9964.

$$I_R= 0.0082+0.4574.\ T\text{-}0^{.5260} \quad \dots (5)$$

Where I_R is the Infiltration Rate in cm/min., and t is the time in minute.

Validation of Models

Figure (7) shows good agreement between predicted results based on equation 4 and the calculated results of cumulative infiltration versus cumulative time. Similarly

Figure (8) shows good agreement between predicted values based on Equation (5) and that calculated of infiltration rate versus cumulative time.

The overall results Figures (7 and 8) are close to the ideal infiltration curves shown in Figures (1 and 2), where the state of soil was initially dry then with continuous progress in flooding became close to the state of saturation.

A comparison between the obtained results and the results collected for different types of soils and from other references is demonstrated in Figure (9). The obtained curve is close to that of sandy soil. The R^2 value of the obtained curve and curve of sandy soil is 0.7390, while R^2 between the obtained curve and that of sandy loam soil is 0.7544 indicating that the tested soil is close to a sandy loam.

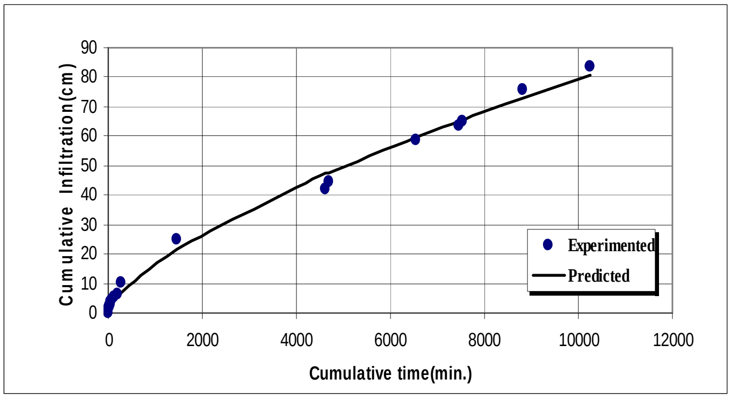


Figure (7) Validation of Mathematical Model for Cumulative Infiltration versus Cumulative Time.

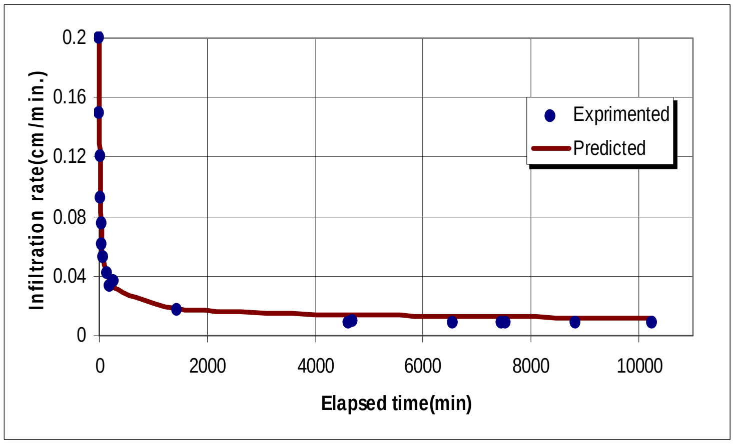


Figure (8) Validation of Mathematical Model for Infiltration Rate Versus Cumulative Time.

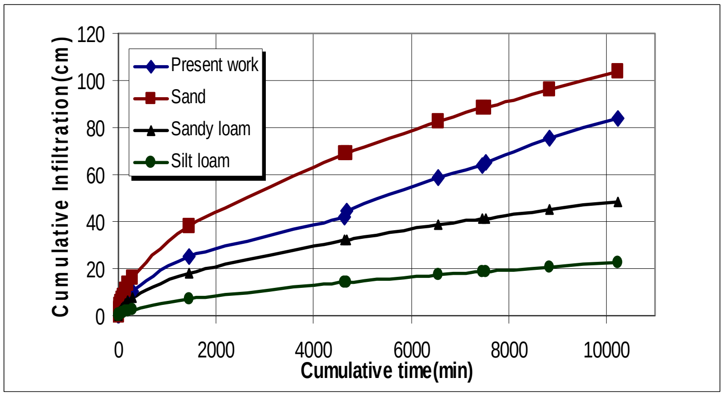


Figure (9) Comparison between the Typical Cumulative Infiltrations and Field Infiltration Curve.

ESTIMATION OF WATER LOSS BY INFILTRATION

The seepage loss from artificial lake in study region can be calculated from infiltration test, this loss is variable with advance of infiltration processes. Depending on the four stages of infiltration processes, the infiltration rate becomes constant after 9000 minutes (6 days and 6 hrs), the cumulative water infiltration during this time is about 74 cm and the expected surface area of artificial lake is (69000 m^2), then the quantity of water loss during this time is:

Quantity= 69000*(74/100) = 51060 m^3

After 9000 minute of infiltration test the rate of infiltration became about 0.0082 cm/minute, then the daily loss of water from the lake is:

Infiltration losses= $0.0082*10^{-2}*60*24*69000 = 8147.52\ m^3$ / day.

CONCLUSIONS

The infiltration of water through a bed of gypseous soil like Najaf soil is complex because it consists of dissolving some salts, suspending and migrating of fine particles from one level to another. Based on these arguments the following points are drawn from the analysis of the flooding:

1- The cumulative infiltration in cm for the four stages demonstrated an increasing trend with increasing cumulative time. This is in close agreement with the ideal shape in terms of the pattern of function.
2- The ideal relationship between the cumulative infiltration and time for tourist city soil is given in Eq. 3. Predicted results are in close agreement with those measured in the field.

3- The infiltration rate of the first stage is higher compared to the other stages of the same stage of flooding (0.2 cm/min to 0.0338cm/min). This was common in the three stages of flooding when the soil is initially dry.

4- Most of loss in water of the lake is due to infiltration, about 8000 m^3/day .

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