EFFECT OF WATER HEAD ON THE INFILTRATION CHARACTERISTICS BY USING THE LABORATORY TESTS

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Abstract

The infiltration characteristics of the soil are an important component of the hydrological conditions. They are one of the components of the water balance and are necessary to describe the runoff response by a runoff model, in addition to describe the effect of water movement on the changing of the soil properties within infiltration.

The present work emphasis on the characteristics of the infiltration by using laboratory model. This model is performed on the remoulded sample of specific density for different heads of water, 10, 20, and 30cm. The results revealed that there are significant effect of the water head with high interaction of the wetting conditions of the soil sample. A comparison was made with the results of field infiltration work, made by Mohammed Sh. Al Shakerchy, 2006. A statistical analysis was made to develop a relationship among the different studied parameters and between the field and laboratory works.

Keywords: soil, infiltration, rate of infiltration, water head, seepage.

تأثير ارتفاع الماء على خصائص الترشح باستخدام الفحوصات المختبرية

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الخلاصــة

إن خصائص الترشح للتربة هي من مركبات الظروف الهيدرولوجية، حيث إنها من مركبات التوازن المائي وهي أيضا ضرورية لوصف المياه الجارية فوق السطح في الموديلات الصغيرة، بالإضافة إلى وصف دور حركة الماء في تغيير خصائص التربة التي يخترقها الماء.

العمل الحالي يؤكد على خصائص الترشح باستخدام الموديل المختبري. هذا الموديل تم على نموذج تربة مقولب بكثافة معينة معرضة لعمود ماء بارتفاعات مختلفة، ١٠، ٢٠، و٣٠ سم. النتائج كشفت انه هناك تأثير واضح لارتفاع عمود الماء مع ارتباط بحالة الترطيب لنموذج التربة. تم مقارنة النتائج مع عمل حقلي من قبل محمد شاكر الشكرجي، ٢٠٠٦. قمنا بتحليل إحصائي للنتائج لتطوير علاقة رياضية لمختلف الخصائص المدروسة، وأيضا بين العمل الحقلي والمختبري

Symbols

SP: Poorly Graded Sand;

I: cumulative infiltration in cm^3/cm^2;

T: time;

a, b, c, and d: constants;

H: Water Head;

USCS: Unified Soil Classification System.

Introduction

The movement of water into soil is called infiltration, whereas, downward movement of water within the soil is called percolation.

The movement of water in soils is a complicated phenomenon to be described because soil surfaces interact with the water being transferred and the soil changes during the water movement process. Water can move in either the liquid or vapor phase, with the latter being more important for relatively dry soil. Various driving forces in water flow exist in the soil, including differences in water content, salt content, temperature, and void size distribution. An overall description is required to encompass this flow system.[4]

Water movement or moisture transfer in soils may be divided into two particular systems for general consideration: -[4, 12, 13]

a) The saturated system where all the voids are filled with water, and

b) The partially saturated system where both air and water are present.

For partly saturated soils, the mechanism for moisture transfer will depend upon whether the system is relatively dry or relatively wet. In the former, vapor transfer is greater than liquid transfer. This is especially important if large temperature gradients exist. In the latter case, where the soil-water system is relatively wet, liquid transfer is generally considered as viscous flow. Diffusive flow due to physicochemical gradients is generally taken to be minor and insignificant in computations of liquid transfer. The absence of a vapor phase in saturated systems indicates that the movement of water in such systems is effected solely by liquid transfer.[4, 12, 13]

Water entering a dry soil at the surface does not saturate the soil below and moves through unsaturated soil. “Unsaturated flow is thus the most common type of flow in soils”, but saturated flow is generally easier to describe. Even “saturated” soil rarely has all its voids filled with water. It is no unusual to expect from 2 to 12 percent of air remaining in the voids.[4, 8]

In groundwater and seepage problems the soil mass is considered as a homogeneous medium of interconnected pores. A material is said to be porous if it contains void spaces in which the material is absent. Pore spaces can be discontinuous or entirely continuous. Sands as an example of porous material are composed of microscopic particles that may be rounded, sub-angular or angular in shape. Numerous voids of varying shapes and sizes exist between the individual particles. Each pore is connected by constricted channels to other pores. In steady-state flow, the soil is assumed as near to being saturated as possible to allow for the flow to occur.[4]

Introduction Into Soils In The Field:

Infiltration is the downward entry of water into the soil. The infiltration rate is the rate at which a soil, in a given condition, can absorb water. It is defined as the volume of water passing into a unit area of soil per unit time, with dimensions of velocity (LT^{-1}). The infiltration velocity is the actual volume of water moving downward into the soil per unit area per unit time.[4]

The infiltration rate obviously depends upon both surface and subsurface conditions. The most important for infiltration rate is stability of pores in the surface layers of soil and water transmission rate of the soil body. Either the surface or the subsurface may limit infiltration rate, and their relative importance depends upon the particular soil. The initial water content of the soil has a large influence on initial infiltration.[4]

The infiltration rate is generally highest when the soil is dry. As the soil becomes wet, the infiltration rate slows to the rate at which water moves through the most restrictive layer, such as a compacted layer or a layer of dense clay. Infiltration rates decline as water temperature approaches freezing. Little or no water penetrates the surface of frozen or saturated soils.[10, 12]

An ideal infiltration curve, based on theoretical analysis, is illustrated in Fig. 1, whereas Fig. 2 shows the ideal infiltration rate with time.[10, 12]

The internal water movement in most gypseous soils is normally moderate to rapid, except where gypsum incrusted layers impede the downward movement of water.[11] Permeability also varies with soil texture. Permeability is generally rated from very rapid to very slow. This is the mechanism by which water reaches the subsoil and rooting zone of plants. It also refers to the movement of water below the root zone. Water that percolates deep in the soil may reach a groundwater aquifer.[11]

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. Several empirical equations adequately fit many measurements: -[4]

$$\mathbf{I = a.\, t^{b}} \qquad \text{…(1)}$$

Or:

$$\mathbf{I = ct^{1/2} + d} \qquad \text{…. (2)}$$

Where I is the cumulative infiltration in cm^3/cm^2; t is time; 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.[4]

Laboratory Work

Preparation of The Laboratory Work

The work was included a set of laboratory infiltration tests on a remoulded sample from certain location in Al-Najaf city. The sample was remoulded in a special container had been made for this work as detailed below. The tests was made by subjection the surface of the remoulded sample to the head of water and observation the lowering of the water surface at certain period of time which refers to the infiltration of water into the soil. The head of water above soil surface was varying to study the effect of the head on the infiltration characteristics, the water heads were 10, 20, and 30 cm where the remoulded soil sample was of 10 cm in thickness.

Materials and Equipment

The laboratory model consists of rectangular cross section metal container of dimensions 41cm x 40.5cm x 100cm depth, as shown in Fig. (3) and Plate (1).
The remoulded soil sample, which was collected manually from Al Adalah district in Al Najaf city, was placed in the container with constant thickness of 10 cm. Table (1) illustrates the properties of the soil used in the tests. Figure (4) shows the results of the grain size distribution of the sample, the figure obviously shows that the soil is within the sand range where sand is more than 85 % of the sample. The soil is classified as SP according to Unified Soil Classification System (USCS)
The water used in the infiltration tests was potable from water supply of the laboratory with total dissolved salts (TDS) is 920 ppm.

Test Program

Table (2) illustrates the program of the tests with time of start and end of the flooding process to form the water head on the soil sample, and then monitoring the lowering of the water head with time. The program included three tests for different values of the water head.
The first and second tests was performed at one day period where the third one was performed after 3 days period from the second one. The average time period of the flooding process for the first and second tests was about 3 minutes and 8 minutes for the third one.

<u>Results and Discusion</u>

Results of Test No. 1

Figure (5) shows the results of first test with water head of 10 cm subjected to the remoulded soil sample in the container, the figure illustrates the relationship between the cumulative infiltration in mm and cumulative respective time in minute. One can notice that the infiltration decreases with time because of the wetting processes of the soil, and this is compatible with the ideal field one which describe the infiltration behavior through the soil in field, figure (1), but the values of infiltration in laboratory are less than that in the field and this behavior may caused by the limitations of the infiltration in vertical direction only, while in field, all directions are available. The infiltration continued in decreasing until the next day.

Figure (6) shows the relationship between the infiltration rate (infiltration divided by the time) in mm/minute and time in minutes for head of water equal to 10 cm. It is clearly that this relationship is in decreasing trend with progress of time start from relatively high value, in comparison with the field ideal infiltration rate, figure (2), it is close to the ideal initial dry curve and that is quite true for the condition of the remoulded soil sample.

Results of Test No. 2

Figure (7) shows the results of second test with water head of 20 cm subjected to the remoulded soil sample in the container,

The infiltration changes in a straight trend and that means the infiltration in this case changed with a constant value and that may caused by the wetting situation of the soil, this curve represent a part of the ideal field infiltration, figure (1), which describe the infiltration behavior through saturated zone.

The behavior of infiltration in this test, differs from the first one in trend and values, may affected by the changing of the soil structure that caused by the first one in addition to the wetting processes. The infiltration continued in decreasing until to the next day.

Figure (8) shows the relationship between the infiltration rate (infiltration divided by the time) in mm/minute and time in minutes for head of water equal to 20cm. One can notice that there are approximately constant rate of infiltration with progress of time within narrow range of values (0.12-0.16 mm/min.). In comparison with the field ideal infiltration rate, **figure (2)**, it is close to the ideal initial wet curve and that is quite true for the condition of the remoulded soil sample.

Results of Test No. 3

Figure (9) shows the results of third test with water head of 30 cm subjected to the remoulded soil sample in the container,

The infiltration changes in a straight trend and faster than the previous one, and that may caused by the higher water head (30cm) and also because of there were specific change in soil structure that cause by the leaching process in addition to the wetting situation of the soil, while the third test performed after about three days period from the second one and this may be enough to dry the sample in the model, where the dry soil situation is increasing infiltration.

This curve represent a part of the ideal field infiltration, figure (1), which describe the infiltration behavior through saturated zone. The infiltration continued in decreasing until to the next day

Figure (10) shows the relationship between the infiltration rate (infiltration divided by the time) in mm/minute and time in minutes for head of water equal to 30cm.

One can notice that there are drop in the rate of infiltration within the first 100 minutes of the infiltration then the rate reaches a constant value of about 0.3 mm/minute. This situation of rate verifies the condition of the soil, where the soil change from proportionally dry to wet conditions. The comparison with the field ideal infiltration rate, figure (2), revealed the condition of soil that discussed above.

Comparison of different cases

Figure (11) shows the results of infiltration with time for different water heads. It is obviously that the case of 10cm water is faster than the case of 20cm water especially at start and that rebound to the wet condition of the soil, where the soil was initially dry at case of 10cm water and wetted with progress of infiltration where the two cases of 10cm and 20cm closes to each other at the late time of infiltration. The case of 30cm water is unique, where the infiltration stay higher one in spite of the changing of wetting condition of the soil but with high water head with respect to other cases.

Figure (12) shows the results of the rate of infiltration with time for different water heads. The figure represent clearly the interaction effect of condition of the soil wetting and water head, where the quick rate of infiltration corresponded to the high water head but the wetting condition decreases the rate of infiltration for the case of 20cm water with respect to the lowest water head (10cm) with considering the time period between the two cases where the period between first and second cases was about 24 hours and the period between the second and third cases was about three days.

Statistical Analysis

A statistical analysis was made to relate the different parameters which studied in the research, infiltration, water head, and time. The analysis depends on the development of ideal infiltration equation (Eq. 3) as following: -

$$\left[I = a \cdot T^{b}\right] \quad \ldots (3)$$

The coefficients of the equation presented as variables depending on the water head as

following in Eqs. (4) and (5): -

$$a = -0.626 \ln(H) + 2.511 \qquad (R^2 = 0.61) \quad \ldots (4)$$

$$b = 0.308 \ln(H) - 0.1554 \qquad (R^2 = 0.963) \quad \ldots (5)$$

where: H: water head

comparison between laboratory and field infiltration

Figure (13) shows a comparison between the results of field and laboratory tests for infiltration. The field work was performed by Mohammed Sh. Al Shakerchy[1] on Al Najaf city soil in the main intersection of the city (near the 20^{th} revolution square) to find out the characteristics of infiltration and its effect on the strength characteristics. The soil was classified as SP according to USCS. The test was made by fill a pit of dimensions 5.5m x 8m

with water using a tank vehicle of 8000 liter, then the water infiltrations were recorded with time. The test was repeated 15 times.

It is clear that there is large difference between the two models and that may rebound to many reasons like the conditions of soil and environment. The properties of the soil (density, permeability, structure, stratification, …etc) have the main effect on the infiltration which some of these properties affect positively like permeability and others affect negatively like density and stratification. The conditions of environment represented in the temperature of the weather, where the increase in water temperature decrease the viscosity of the fluid and increase the infiltration and in the same time, the high temperature causes the evaporation process of the water. These conditions are controlled in the laboratory and can change for different conditions of the field oppositely the uncontrolled field conditions.

In the laboratory model the infiltration was limited in the vertical direction only where the field test was unlimited in specific direction and this is the main reason of high difference between the two models.

Figure (14) shows the relationship between the time and the percent of the laboratory infiltration to the field infiltration. This relationship is in increasing trend with time. Equation (2) relate the percentage ratio of the laboratory to the field infiltration with time and R^2 =0.91. this equation is useful to predict the field infiltration from the laboratory work.

Conclusions

From the previous articles, the following points are concluded: -

1- There were clear effect of the water head, that subjected to a soil, on the infiltration, processes and the rate of the infiltration where with increasing the water head, the infiltration increases with same initial conditions of the soil.

2- The infiltration and rate of infiltration are change with time where the wet condition of the soil was progressing and that is for all tests of all different water heads.

3- There were a huge difference between the laboratory and field results and that is return to different causes, such as, the soil conditions, which includes the density and permeability, and the temperature of the water. The infiltration in the field conditions is included the entering of water into the soil in different directions where the infiltration in laboratory conditions is restricted in vertical direction only.

4- As a result of the statistical analyses on the laboratory work, an equation was found to relate the time, infiltration, and water head with good R^2.

5- A good equation with acceptable R^2 (0.91) relate the laboratory work and the work.

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Acknowledgment

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Rffernces

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Relationships - Part III".

Table (1): Properties of the Soil Used in Tests.

Soil Density, gm/cm3	Specific Gravity	Water Content, %	Void Ratio, e
1.8	2.68	10	0.638

Table (2): Tests Program.

Test No.	*Water Head, cm*	*Date*	*Time of Flooding Start*	*Time of Flooding End*
1	10	14/2/2007	10:48 AM	10:51 AM
2	20	15/2/2007	09:32 AM	09:35 AM
3	30	18/2/2007	10:32 AM	10:40 AM

Note: All Soil Samples with Thickness of 10cm.

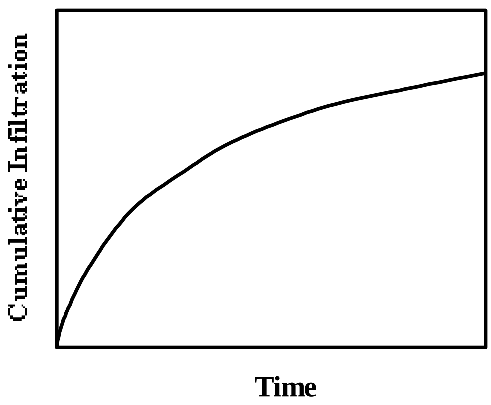


Figure (1): Ideal Infiltration Curve.[10, 12]

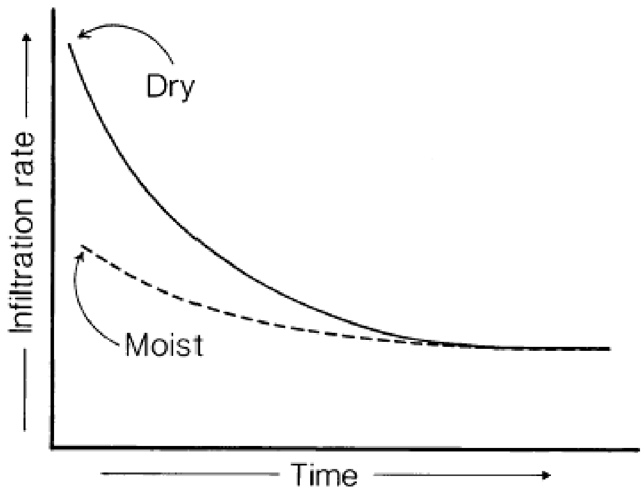
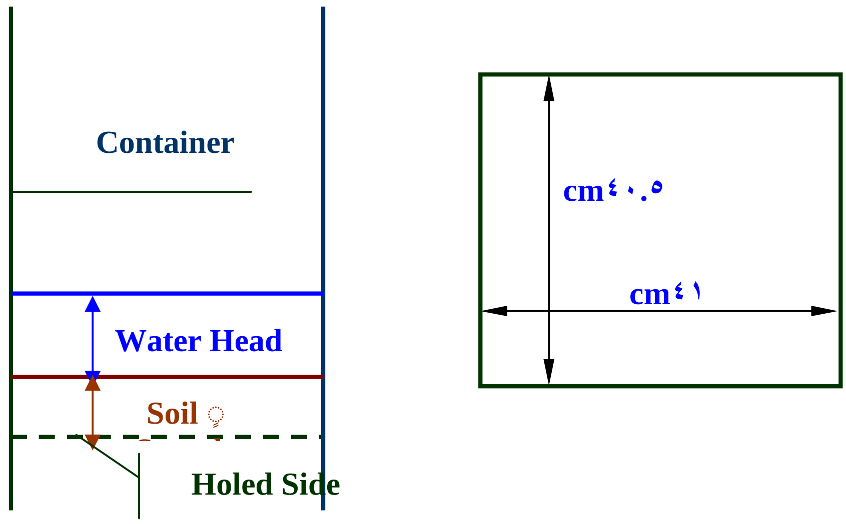


Figure (2): Ideal Infiltration Rate Curve.[10, 12]



a- Vertical Section **b- Horizontal Plan**

Figure (3): Details of the Container.

Plate (1): The Metal Container.,

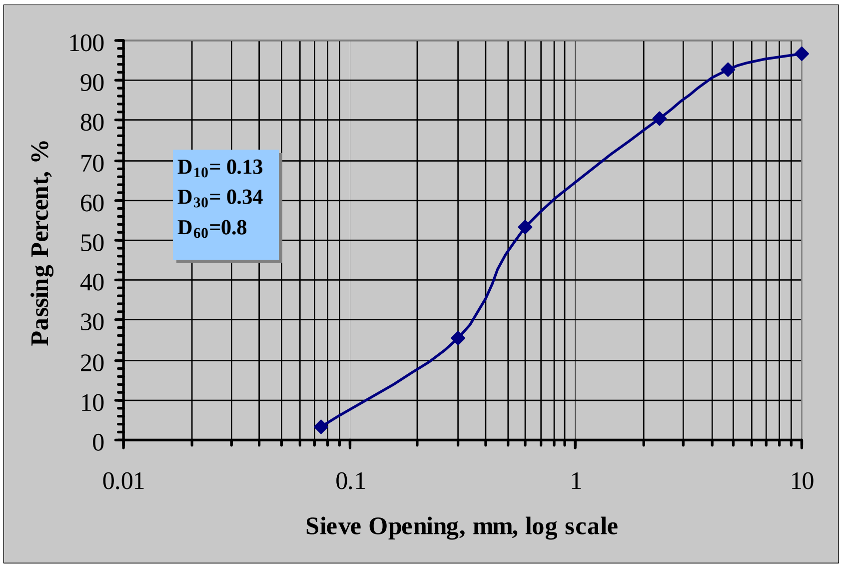


Figure (4): Grain Size Distribution of the Soil Used in the Tests.

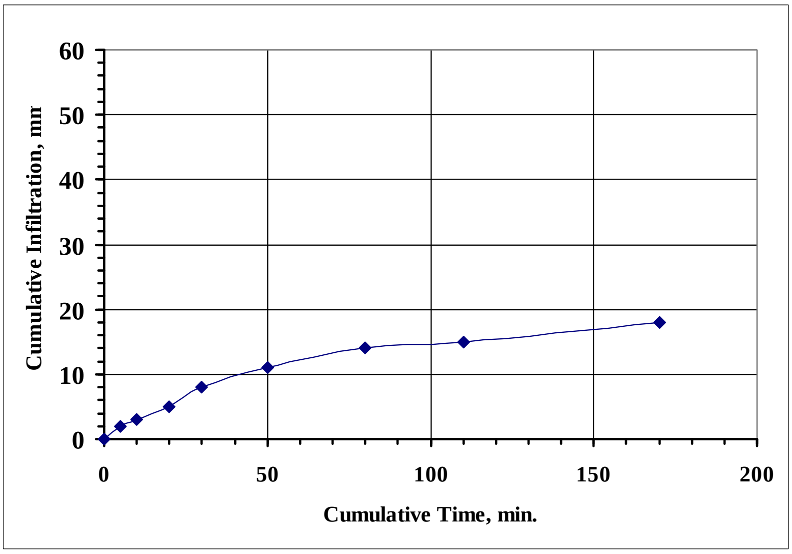


Figure (5): Relationship between Cumulative Infiltration and Time for Water Head of 10 cm.

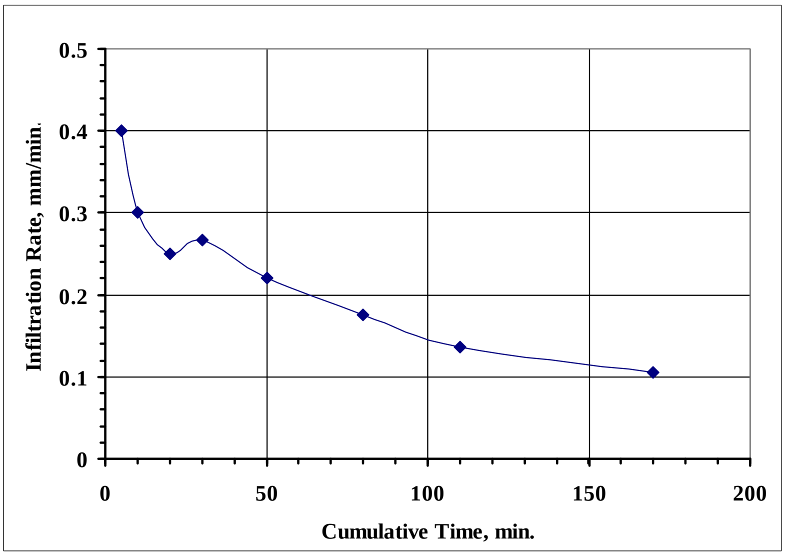


Figure (6): Relationship between Infiltration Rate and Time for Water Head of 10 cm.

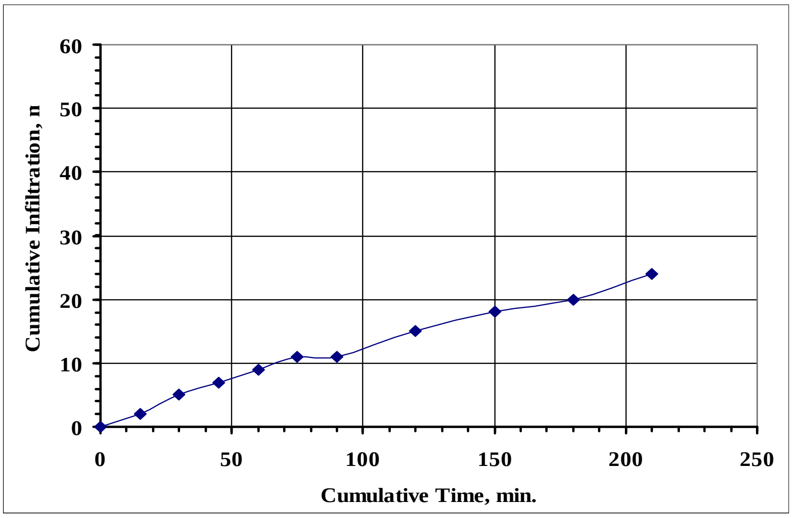


Figure (7): Relationship between Cumulative Infiltration and Time for Water Head of 20 cm.

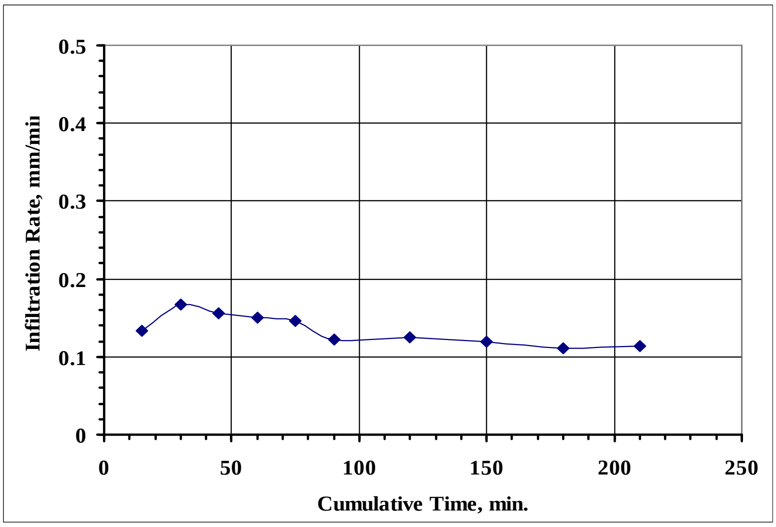


Figure (8): Relationship between Infiltration Rate and Time for Water Head of 20 cm.

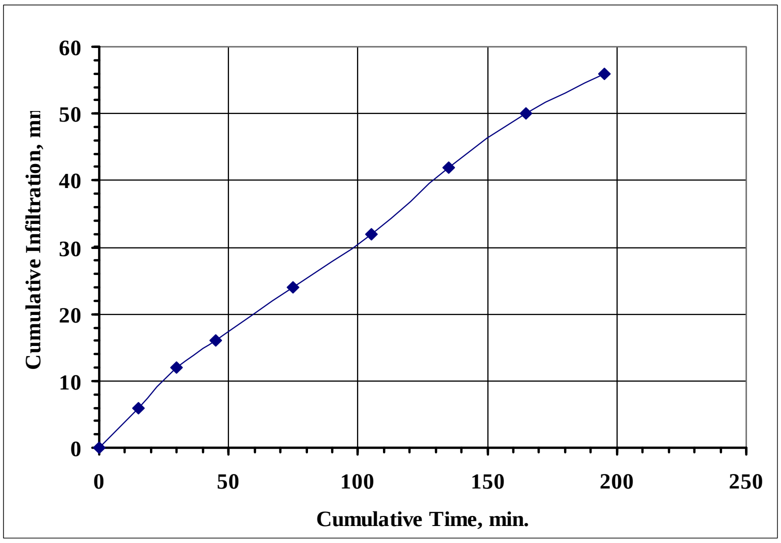


Figure (9): Relationship between Cumulative Infiltration and Time for Water Head of 30 cm.

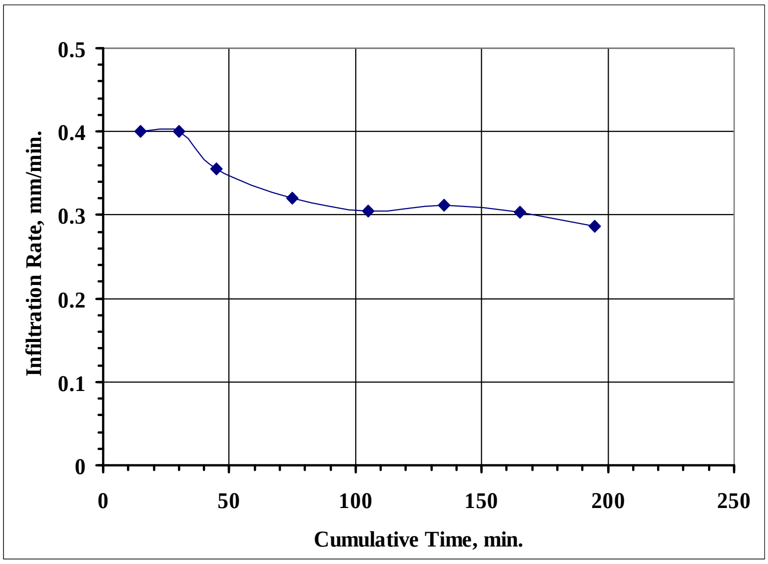


Figure (10): Relationship between Infiltration Rate and Time for Water Head of 30 cm.

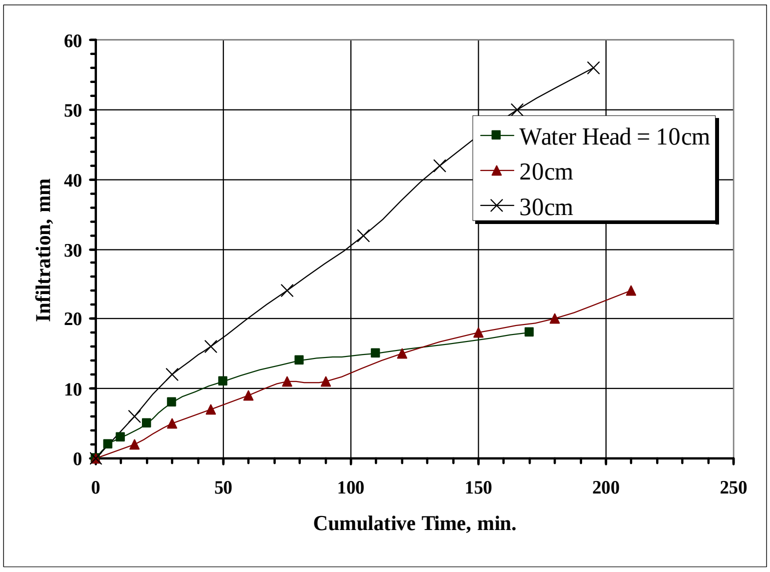
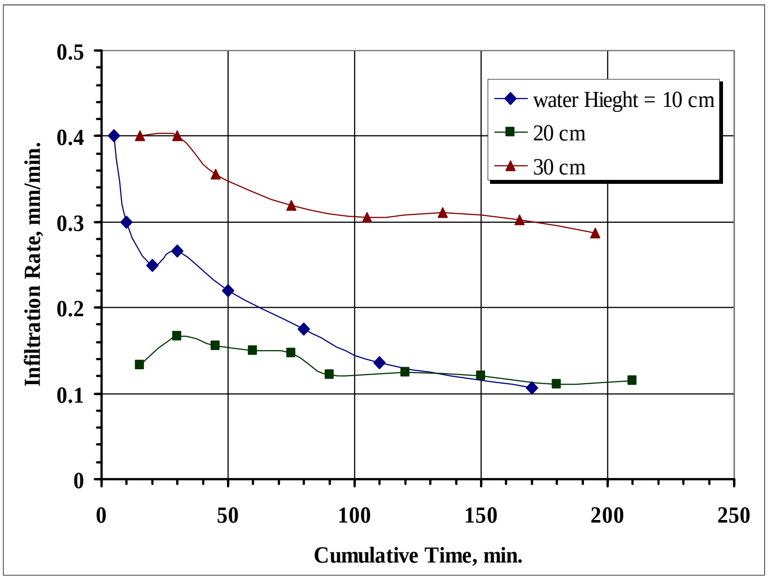


Figure (11): Relationship between Cumulative Infiltration and Time for Different Water Heads.



Figure(12) Relationship between Infiltration Rate and Time for Different Water Heads.

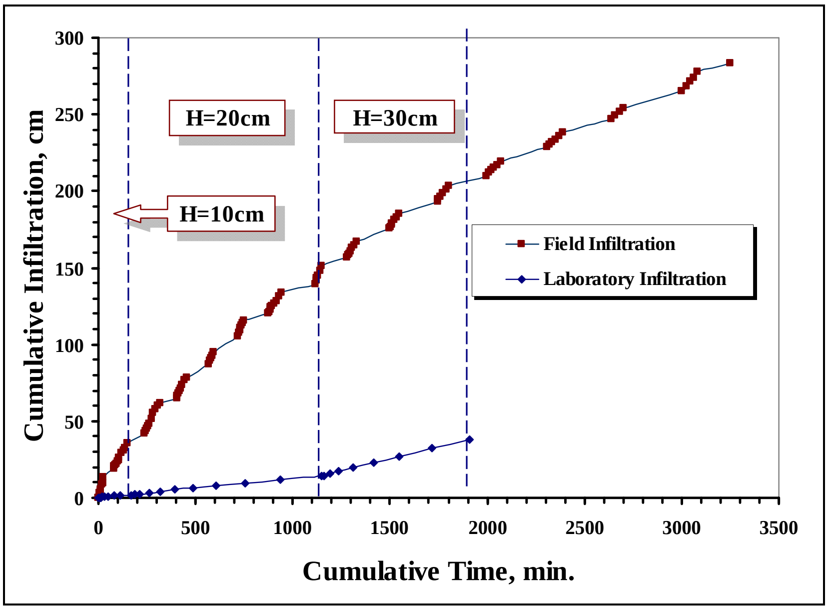


Figure (13): Relationship between Cumulative Infiltration and Time in Field and Laboratory Tests.

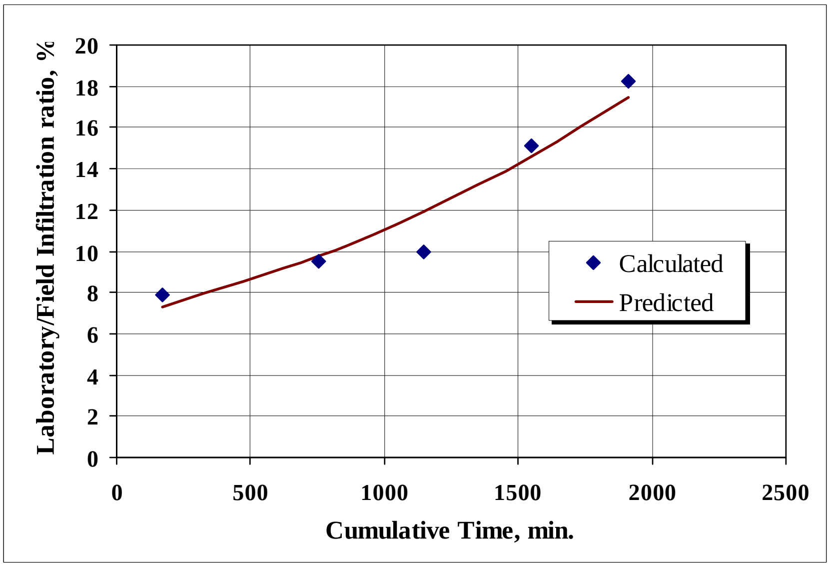


Figure (14): Relationship between Cumulative Time and in Field and Laboratory Tests.