Effect of Temperature Variation on Seepage Flow and Factor of Safety

Abdul Kareem Esmat Zainal
Assist. Prof.
Baghdad University / College of Eng./ Civil Eng. Dept.
Email: kareem_esmat@yahoo.com

Abstract:

Seepage of water through soils can be affected by the temperature variations; the temperature variation is directly related to the hydraulic conductivity (*k*) which represents the ability of water to percolate through soil voids.

A case of water flow under dams was taken as an example, it was simulated using Geo-Slope (SEEP/W) 2007 computer program, the variation of hydraulic conductivity *k*(T) (hydraulic conductivity as a function of temperature) was computed using Add-In feature in SEEP/W as an additional user defined function that can be used similarly to the other functions that were supplied by the computer program.

Temperature of 40°C–50°C was used to represent ground surface (typical average temperature during summer season in Iraq) with initial temperature of 20 °C for inside soil (for a period of six months 180 days) to show the variation of flow quantity in m^3/day besides others, the variation of water flow was shown to be about 44.94%, the variation of exit gradient was about 16.94%, and the variation in F.O.S. against heave was about 14.49%.

Keywords: Seepage Flow, Hydraulic Conductivity, Temperature Variation Effect on Soil.

Introduction and Review

Water seepage through soils is one of the subjects that had many applications in soil mechanics (e.g. dams, embankments, sheet piles, etc.). Analysis of this subject was discussed by many authors [1][2][3][4][5][6].

Heat flow in soils involves several different ways:

i) Convection,
ii) Radiation, and
iii) Conduction.

Convection takes place when a fluid flows over a solid that is at a different temperature than the fluid. Radiation refers to the fact that all bodies continuously emit energy because of their temperature. This energy propagates to other nearby fluids or bodies through electromagnetic waves. Conduction is a heat transfer mechanism whereby energy moves from a region of high temperature to a region of lower temperature. The phenomenon is due to the motion and impact of molecules, which increase as the temperature rises. Conduction of heat in soil is very similar to the flow of water through soil and is the most important mechanism of heat transfer through soils.

The hydraulic conductivity is one of the most important soil properties that affect the water flow through soil particles; its value depends on two main factors, which are:

i) Soil structure, and

ii) Water viscosity.

This is clearly shown in equation (1)[2]:

$$k = \frac{\gamma_w}{\eta} K \qquad (1)$$

where:

k= Hydraulic conductivity,

K= absolute or specific permeability, and

η= water viscosity.

Table. 1 shows the variation of viscosity relative values to the value of 20°C, this can be represented by the chart in **Fig. 1[2].**

Table. 1 Variation of $\eta_{T°C}/\eta_{20°C}$

Temperature, T (°C)	$\eta_{T°C}/\eta_{20°C}$	Temperature, T (°C)	$\eta_{T°C}/\eta_{20°C}$
15	1.135	23	0.931
16	1.106	24	0.910
17	1.077	25	0.889
18	1.051	26	0.869
19	1.025	27	0.850
20	1.000	28	0.832
21	0.976	29	0.814
22	0.953	30	0.797

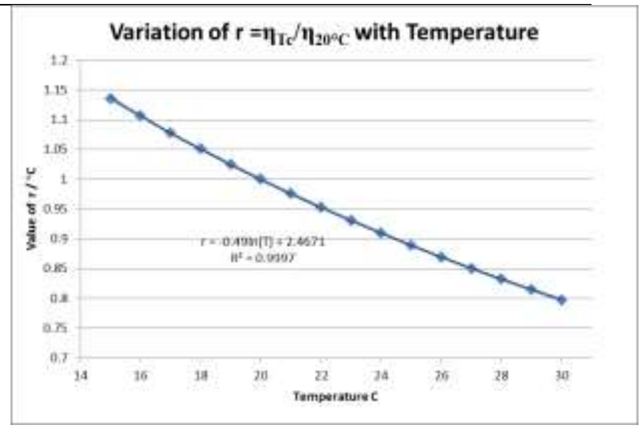

Fig. 1 variation of viscosity ratio

The variation of $\eta_{T°C}/\eta_{20°C}$ can be mathematically represented by equation (2).

$$r = 2.4671 - 0.49 \times Ln(T) \qquad (2)$$

where

r = ratio of $\eta_{T°C}/\eta_{20°C}$

The equation had an excellent correlation with the original data represented by **[2]** with R^2=0.9997.

Present work

A solved example after **[2]** was used to show the effect of temperature rise effect on hydraulic conductivity, hence the flow rate; the exit gradient; and factor of safety against heave.

The example shows a concrete dam that has a cutoff wall with water flowing under the dam as shown in **Fig. 2.**

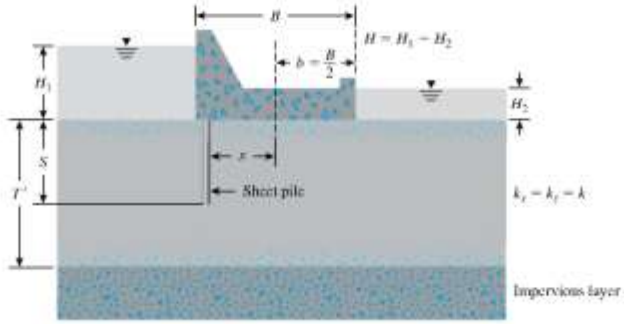

Fig. 2 Dam Dimensions

Other dimensions are:
$H=H_1-H_2=5m$
Cutoff depth S=3m
Depth of permeable soil layer T`=6m
Width of dam B =6m
x=2.4 m
L=120m
k=0.008 cm/sec = 6.912 m/day. (modified to 0.06912 m/day) to be more realistic.

Geo-Slope SEEP/W 2007 and TEMP/W **[4]** computer program was used to simulate the example as shown in **Fig. 3**.

An upstream total head of 6m was applied and a total head of 1m was applied at downstream to simulate a total head difference of 5m between the upstream and downstream as in the example. This is shown in **Fig. 4** as the result of the analysis.

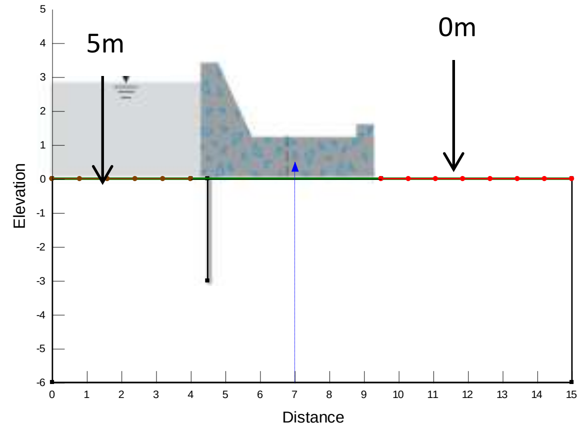

Fig. 3 Hydraulic Boundary Conditions

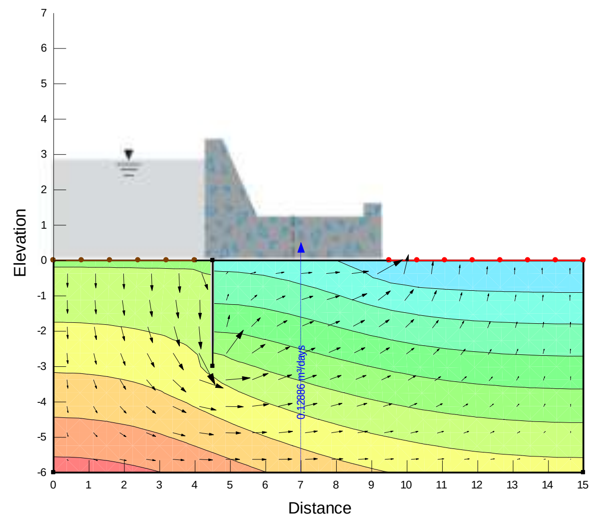

Fig. 4 Results of Simulation

The flow quantity obtained from the computer program was 0.12886 m^3/ day/m which equals to 15.4632 m^3/ day for the whole 120 m of the dam length, against 15.6764 from reference **[2],** the percentage of error between the results obtained from the computer program and the results obtined from the reference with the modified *k* value isshown in equation **(3):**

$$\frac{15.6764-15.4632}{15.6764}=0.013=1.3\% \quad (3)$$

This could be considered as negligible for this study.

Extended analyses were conducted for a period of 6 months (180 days) simulation which is considered as a good representation for the hot summer climate period.

The temperature variations were applied in two different values for two different areas. The first one is considered a hot area with a temperature value of 50 °C located under the concrete dam as shown in figure 5. The other area is the upstream and the downstream areas which were considered warm areas with temperature of 40 °C.

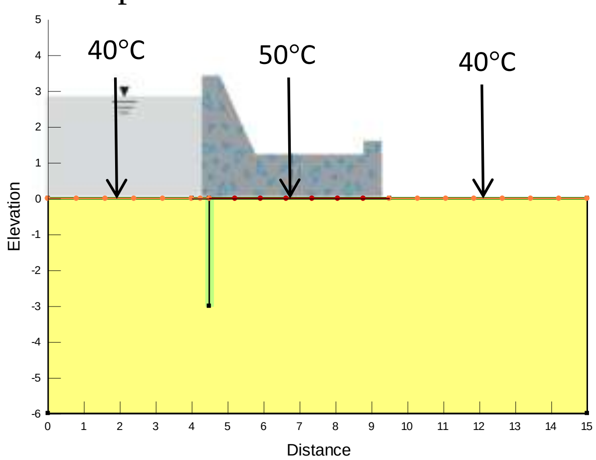

Fig.5 Boundary Conditions for Temperature

The soil heat conductivity was 110 kJ/days/m/°C, and volumetric heat capacity was 2500 kJ/m³/°C which are typical values that are more likely to be used **[4].**

Figures 6, 7, 8, 9, and 10 show the temperature variations and transfer during the period of simulation for 30 days, 60 days, 90 days,120 days, and 180 days, respectively.

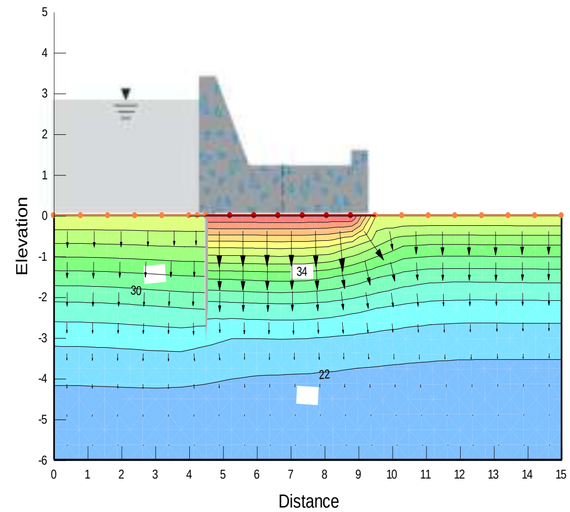

Fig. 6 Temperature after 30 days

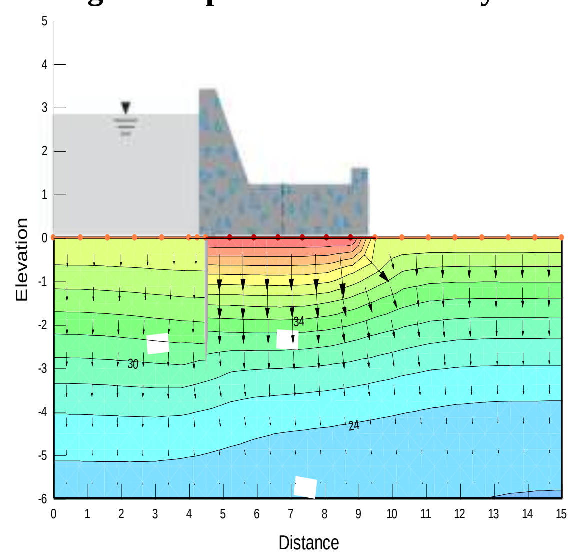

Fig. 7 Temperature after 60 days

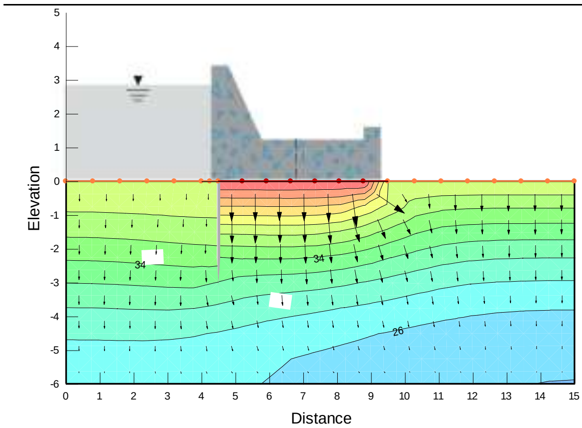

Fig. 8 Temperature after 90 days

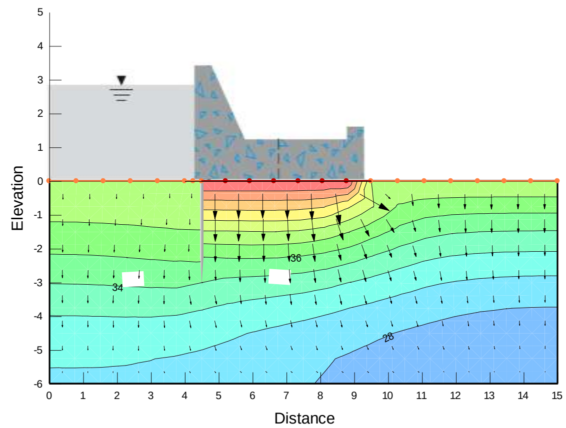

Fig. 9 Temperature after 120 days

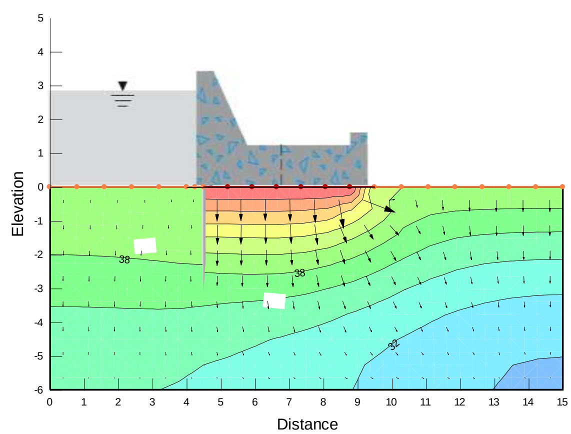

Fig. 10 Temperature after 180 days

Selected nodes are used to show the variation of the temperature across the depth of the soil layer as shown in dark blue color in **Fig. 11**.

Fig. 12 shows the variation of temperature of these nodes with time of 30, 60, 90, and 180 days.

The migration of heat through the soil affects the soil hydraulic conductivity. The variation of the hydraulic conductivity with time for each node in **Fig. 11** is shown in **Fig. 13**.

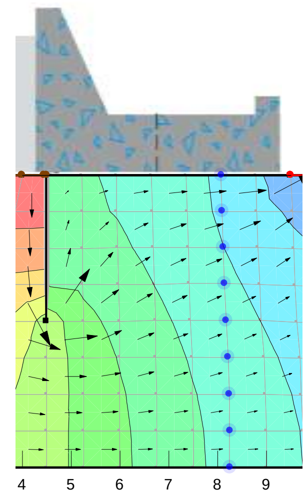

Fig . 11 Nodes used to show results

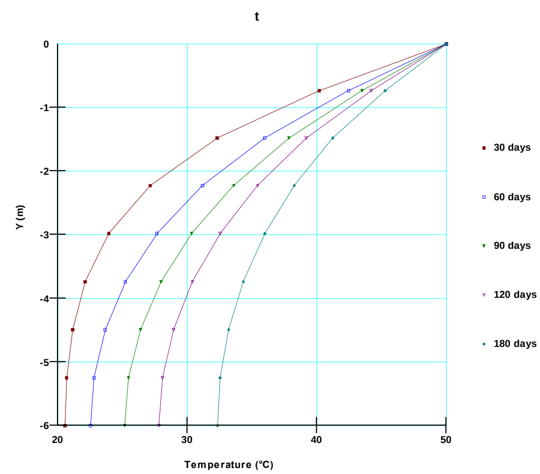

Fig. 12 Temperature Variation

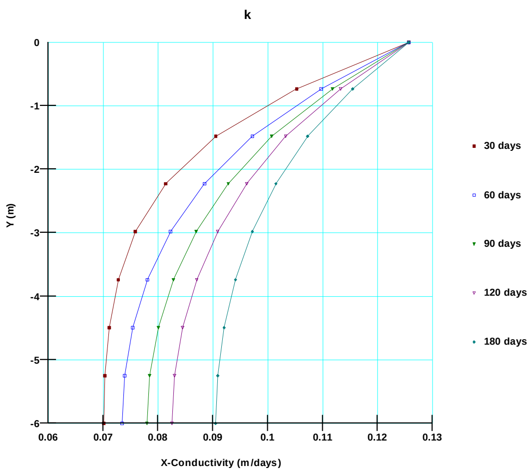

Fig. 13 Hydraulic Conductivity Variation

Fig. 14 shows the node used to express the exit gradient in dark blue color where **Fig. 15** shows the variation of the exit gradient for the whole period of simulation.

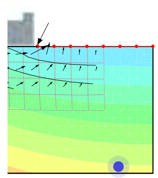

Fig. 14 Exit Node

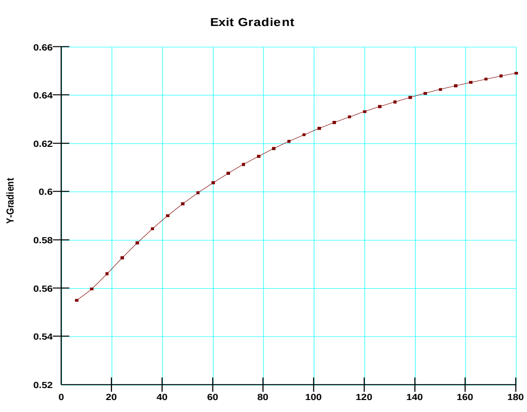

Fig. 15 Exit Gradient

Fig. 16 shows the variation of the exit gradient in addition to the variation of the factor of safety against heave where it is obviously shown that with the increasing value of the exit gradient, there is a decreasing in the value of the F.O.S. the factor of safety was calculated according to equation (4):

$$F.O.S. = \frac{i_{cr}}{i_{exit}} \qquad (4)$$

where:

i_{cr}= critical gradient, and

i_{exit}= exit gradient.

Critical gradient was assumed to be 1 (equation 5) as an average value for soils, if the average unit weight of the soil was assumed to be 20 kN/m^3 and the unit weight of water is 10 kN/m^3 then:

$$i_{cr} = \frac{(20-10)}{10} = 1 \qquad (5)$$

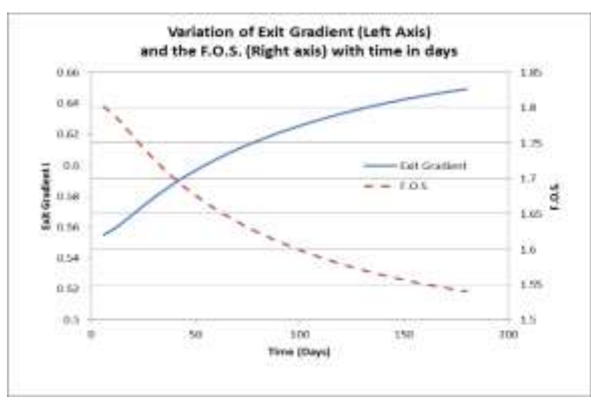

Fig. 16 Variation of Exit Gradient and F.O.S. with time

To show more clearly the effect of temperature and time on gradient, another node was taken as an example which is shown in **Fig. 17**. The variation of temperature and gradient with time is shown clearly in **Fig. 18**

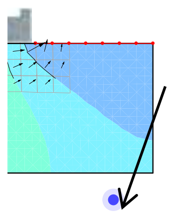

Fig. 17 Node to show gradient variation

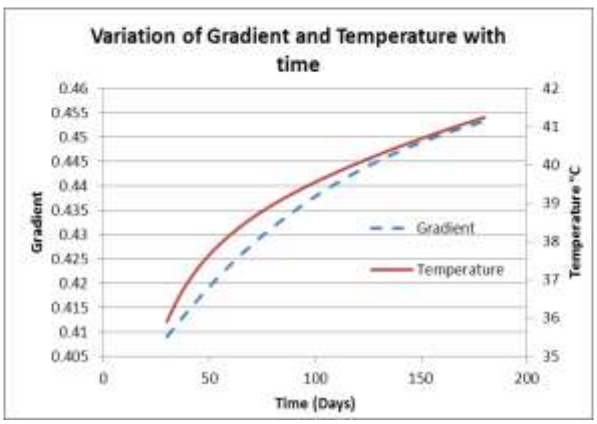

Fig. 18 Variation of Gradient and temperature

Flow quantity variation with time is shown in **Fig. 19** where the increase in flow in m^3/day as a result to the increase in temperature is shown.

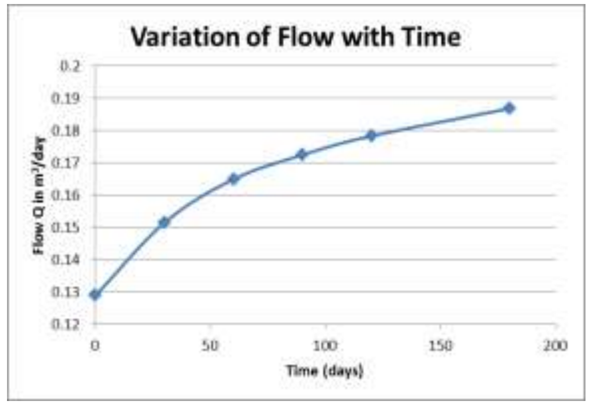

Fig. 19 Variation of flow with time

Results revealed the variation of flow to be as shown in equations (6), (7), and (8):

$$\frac{0.18677-0.12886}{0.12886}\times 100 = 44.9\% \qquad (6)$$

Exit gradient variation to be:

$$\frac{0.649148-0.55509}{0.55509}\times 100 = 16.94\% \quad (7)$$

and the F.O.S. variation to be:

$$\frac{1.80151-1.540482}{1.80151}\times 100 = 14.49\% \quad (8)$$

Finally, the code (in C++) used to calculate the value of the hydraulic conductivity according to the temperature is shown in plate 1.

```
using System;
using System.Collections.Generic;
using System.Text;
using System.Windows;
 namespace  k_calculations
 {
```

```
public class Conductivity_with_Temp
:Gsi.Function
{
 public double k_sat; //k for fully
saturation
         public double Calculate(double
pressure)
{
        double new_k;
        double etemp;
   double modifier;
      etemp =
GetParam(Gsi.DataParamType.eTem
perature);

      if (etemp <= 0)
         etemp = 0.0000001;
   modifier = 2.4671 - 0.49 *
Math.Log(etemp);
   new_k =  k_sat/modifier ;
       return (new_k) ;
}
}
}
```

Plate 1 The code used to calculate the value of hydraulic conductivity with temperature

Conclusions

From all the analyses above, it can be concluded that:

1- The variation of the temperature directly affect the hydraulic conductivity which increases with the increase of temperature due to the decrease in water viscosity, hence the quantity of the water flow under the dam increases and may reach ≈45%.

2- The variation of the hydraulic conductivity also affect the exit gradient due to the of flow velocity, where the exit gradient increases with the increase of temperature, the variation of exit gradient may reach ≈16.94%.

3- Due to the above variations, the factor of safety against heave also affected and become less with increasing of temperature and the variation may reach ≈14.49%.

4- Other soil properties may also be affected by the variation of temperature and also needs to be further studied.

References

[1] Briaud, Jean-Louis, 2013, *"Geotechnical Engineering: Unsaturated and Saturated Soils"*, John Wiley & Sons, Inc.

[2] Das, Braja M., and Khaled Sobhan, 2014, "Principles of Geotechnical Engineering", 8th edition, Cengage Learning.

[3] Farouki, Omar T., 1981, "Thermal properties of soils", United States Army Corps of Engineering.

[4] GEO-SLOPE International Ltd., 2008, "Thermal Modeling with TEMP/W 2007", GEO-SLOPE International Ltd.

[5] Moradi, Ali, Kathleen M. Smits, Ning Lu, and John S. McCartney, 2016, "Heat Transfer in Unsaturated Soil with Application to Borehole Thermal Energy Storage", Vadose Zone Journal, October, pp 1-17.

[6] Murray, E. J., and V. Sivakumar, 2010, "Unsaturated Soils a fundamental

interpretation of soil behavior”, John Wiley & Sons Ltd.

تأثير تغير درجات الحرارة على جريان المياه في التربة ومعامل الامان

عبد الكريم عصمت زينل
استاذ مساعد
جامعة بغداد / كليه الهندسة / قسم الهندسة المدنية
البريد الالكتروني **kareem_esmat@yahoo.com**

الخلاصة

تسرب المياه خلال التربة يمكن له ان يتاثر بتغيرات درجة الحرارة، حيث ان درجة الحرارة تؤثر بشكل مباشر على معامل نفاذية المياه التي تمثل سهولة انسيابية المياه في التربة.
تم استخدام مثال لمياه تنساب تحت سد كونكريتي ل
تمثيل حركة المياه باستخدام برنامج Geo-Slope (SEEP/W) 2007 وذلك لتمثيل التغيرات الحاصلة في قيمة معامل النفاذية k(T) أي قيمة معامل النفاذية كدالة متغيرة تعتمد على درجة الحرارة وتم ذلك باستخدام خاصية Add-In في البرنامج التي تـُمكـّن المستخدم من اضافة الدوال المعرفة من قبله الى البرنامج.
تم استخدام تغيرات في درجة الحرارة من 40 – 50 درجة مئوية (درجة حرارة معتادة خلال اشهر الصيف في العراق) مسلطة من الخارج مع الابقاء على درجة الحرارة داخل التربة على 20 درجة مئوية وذلك لفترة ستة اشهر 180 يوم لبيان مدى تاثير درجة الحرارة على كل من، كمية المياه المنسابة وعوامل اخرى. حيث كانت نسبة التغيير في كمية المياه المنسابة بحدود 44.94% ، وانحدار الخروج 16.94% والتغيير في معامل الامان ضد الارتفاع 14.49%.

الكلمات المفتاحية: جريان المياه في التربة، معامل النفاذية، تغير درجات الحرارة في التربة