EFFICIENCY OF WELLPOINT DEWATERING SYSTEM AS AFFECTED BY HIGH PERMEABILITY LENSES

Hosam El-Din M. Moghazi

Department of Irrigation and Hydraulics, Faculty of Engineering,
Alexandria University, Alexandria, Egypt

ABSTRACT

Thin lenses of a more permeable material are often extended horizontally underneath site excavations. The available equations used to design the wellpoint systems were based on an assumption that the soil is isotropic and homogeneous. A finite element model has been designed to investigate the effect of presence of high permeability lenses on the efficiency of wellpoint dewatering system. This includes the wellpoint pumping rate and the position of the free surface underneath the bottom of excavation. The results indicates that the presence of high permeability coefficient lens can result in an unsatisfactory performance of a wellpoint dewatering system which would have been adequate if the soil is isotropic. The efficiency of the system decreases as the permeability coefficient of the lens increases. Meanwhile, the efficiency of the dewatering systems improves as these lenses are moved far from the bottom of the excavation.

Keywords: Dewatering, Excavation, Finite elements, Lenses, Wellpoint system.

INTRODUCTION

The presence of groundwater on site will have considerable effect on the stability of excavation. Therefore, a pumped dewatering system is often used to lower the groundwater level. Accordingly, the stability of the side slopes is increased, preventing base uplift on the bottom of the excavation. If the dewatering system is not correctly designed, the sides of the excavation may collapse or its base may become unstable, and flooding might also occur. Wellpoint systems are among the most common and economical methods of dewatering excavations. They are quick to install, versatile and can remove large quantities of water in relatively short times. Wellpoints are essentially small wells, with small screens of about 50 mm diameter and up to 1 m long connected by a riser pipe to a common header pipe from which water can be pumped by a self priming vacuum pump. The top of the screen is kept at least 1 m below the deepest part of the excavation. Wellpoints are placed close together at regular intervals around the perimeter of the excavation. The cones of depression for individual wells overlap, and the drawdown within an open excavation can approximate to the level of the wellpoint tips as seen in Figure 1. The spacing between wellpoints depends on the permeability of the soil and the time available to effect the drawdown. The average spacing is about 1, 1.5 and 2 m for coarse gravel, fine to coarse gravel and silty sand respectively. The discharge of wellpoint varies from 2 to 3 m^3/h. Owing to the limitations of suction lift, the maximum drawdown achievable at a wellpoint is about 6 m. Multistage systems are, then, necessary for greater drawdown depths.

The steady state distance of influence R_O of the wellpoint system as shown in Figure 2 is a function of both the recharge characteristics of the aquifer and the drawdown of the wellpoint h_w. Somerville [1] suggested an empirical formula, which has been recommended by other authors [2,3]:

$$R_o = C\ h_w\sqrt{k} \tag{1}$$

where k is the soil coefficient of permeability in m/s and C is a factor of between 1500 and 2000 for plane flow. The units of R_O and h_w are in meter. The quantity of water that has to be pumped to obtain the required drawdown depends on permeability, aquifer type and source of water (e.g. radial or line source). Somerville [1] presented equations for estimating the quantity of total discharges from wellpoint systems as well as the corresponding drawdowns. For instance, at a double row of wellpoints of an unconfined aquifer midway between two parallel and equidistant line sources (see Figure 2), Somerville's equations take the forms;

$$Q_s = \left[\left(0.73+0.27\frac{(H_o-h_o)}{Ho}\right)\frac{kx}{R_o}\left(H_o^2-h_o^2\right)\right] \tag{2}$$

$$h_D = h_o\left[\frac{C_1C_2}{R_o}(H_o-h_o)+1\right] \tag{3}$$

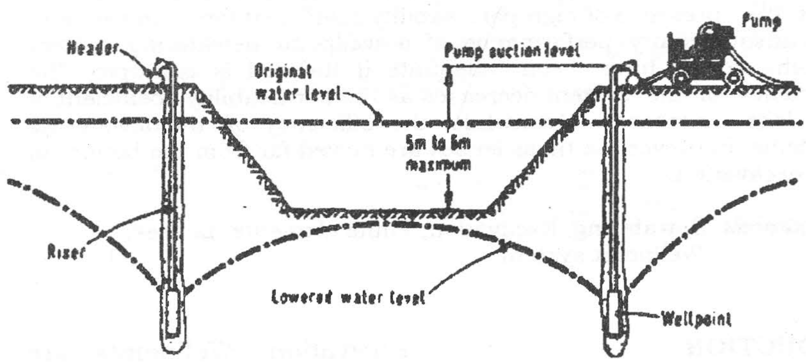

Figure 1 Effect of wellpoints dewatering system on both sides of an excavations

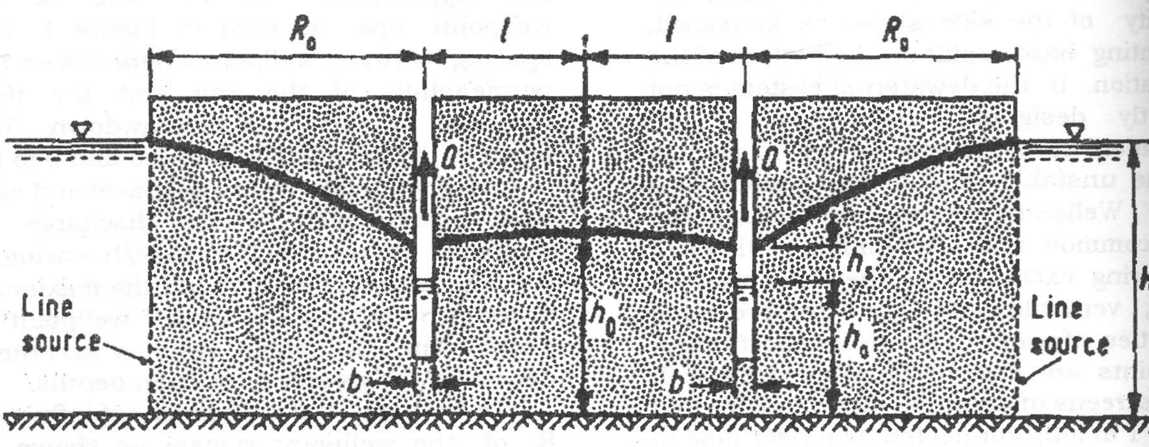

Figure 2 Dewatering system by a double row of wellpoints between

where:

Q_s= total discharge from a pair of wellpoints (m^3/s).

x= length of excavation (1 meter run).

H_o= depth of impermeable layer below original water table (m).

h_o= height of water table in wellpoints (m)

C_1 and C_2= coefficients can be obtained from charts and depend on the water table conditions and the geometry of the system.

h_D= height of water table at the mid-distance between two wellpoints (m)

These equations were developed based on the assumptions that the soil is isotropic and uniform. Plane flow net method can also be used to estimate flow rate. However, when strata of soil having different permeability are presented these methods are less easy to apply. In some instances, very thin layers (lenses) of a more permeable material are extended horizontally underneath the site excavation. They may have a serious effect on the efficiency of the dewatering system. The finite element technique has the flexibility to handle the free surface groundwater flow problems in anisotropic soil [4-7].

This research aims at investigating the influence of presence of high permeability lenses on the effectiveness of a wellpoint dewatering system, using the finite element method.

THEORETICAL APPROACH

The steady state behaviour of the groundwater flow in a porous media can be described in two-dimensions by the following equation [5]:

$$\frac{\partial}{\partial x}(k_x\frac{\partial \phi}{\partial x})+\frac{\partial}{\partial y}(k_y\frac{\partial \phi}{\partial y})+Q=0 \qquad (4)$$

where ϕ is the potential head, k_x and k_y are the permeability coefficient in the x and y directions. The following two boundary conditions for Equation 4 are generally encountered in groundwater flow:

Specified head boundary condition; where the head to be specified at a nodal point on the boundary S_A

$$\phi = \phi_P \qquad (5)$$

in which ϕ_P is the prescribed head.

Specified flux boundary; where a specified amount of flux q_o flows into the domain per unit length of boundary S_B

$$k\frac{\partial \phi}{\partial n}+q_o=0 \qquad (6)$$

where $\partial/\partial n$ is the outward pointing normal derivative to the boundary. Applying the Galerkin [4] residual approach to Equation 4 yields set of simultaneous equations;

$$[K]\{\Phi\} = \{F\} \qquad (7)$$

where [K] is the global stiffness matrix, $\{\Phi\}$ is the global vector of unknown head to be determined and {F} is the global nodal force vector. Applying the appropriate boundary conditions to Equation 7 the unknown heads can be determined. The total flow rate can be obtained by summing the nodal reactions across faces AB or CDEF on which the value of Φ is prescribed. More details about the finite element equations are available elsewhere such as Hinton [8] and are beyond the main purpose of this study.

GEOMETRY AND BOUNDARY CONDITIONS

The layout of the typical wellpoint system whose performance was investigated is shown in Figure 3. There are two lines of wellpoints, 30 m apart, and the total depth of each wellpoint is 7 m. The original water table is assumed at the ground level. The capillary effects were neglected and, therefore, the soil above the free surface did not feature in the analysis. The soil permeability coefficient is assumed equal $2x10^{-5}$ m/s. The maximum drawdown h_w at a wellpoint is 6 m. According to Equation 1 with C = 1500 to 2000, the average distance of influence of the wellpoint lines R_O is about 47 m. The depth of excavation is 4 m below the ground level. A thin lens of higher permeability coefficient k_2 is located at a depth T below ground level. It has a thickness of 0.20 m. The soil at a depth H_o equal 40 m from the ground level has been taken as impermeable.

Referring to the geometry of the model in Figure 3, the boundary conditions associated with the flow towards the wellpoint system are as follows:

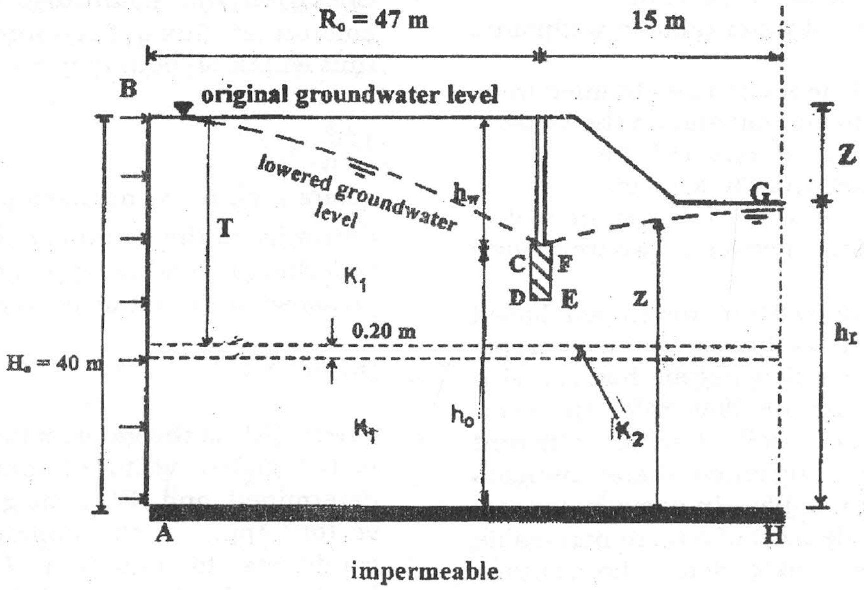

Figure 3 Cross section through wellpoint dewatering system

Free Surface

Along the boundaries BC and FG the gauge pore water pressure equals zero and, accordingly, the total head ϕ equals the elevation head z above the datum:

$$\phi = z \qquad \text{(along BC and FG)} \qquad (8)$$

In addition, the flow across these boundaries is nil

$$\frac{\partial \phi}{\partial n} = 0 \qquad \text{(along BC and FG)} \qquad (9)$$

Water Boundaries

Along the faces AB and CDEF the total head Φ equals to the elevation of the water face above the datum:

$$\phi = H_o \qquad \text{(along AB)} \qquad (10)$$

$$\phi = h_o \qquad \text{(along CDEF)} \qquad (11)$$

Impervious Boundaries

Since the face AH is impervious, the flow across it is nil;

$$\frac{\partial \phi}{\partial n} = 0 \qquad \text{(along AH)} \qquad (12)$$

Also, along the boundary GH, $\partial\phi/\partial n = 0$ due to the symmetry condition.

ANALYSIS

The steady state drawdown produced by the wellpoint system was investigated using the finite element method. Figure 4 shows a typical finite element mesh used to investigate the problem. The Taylor and Brown iterative technique [9] was applied to determine the position of the free surface, in which the elevation of each node z along the free surface was adjusted until the condition of zero gauge pore water pressure was fulfilled (Equation 8). Different values of the permeability coefficient of the thin lens k_2

were investigated (k_2/k_1 = 1, 10, 100, 200, 400 and 800). At each value of k_2/k_1 three different positions of the thin lens were also investigated (T = 10, 20 and 30 m). In each case, the depth Z_a of the highest point on the free surface underneath the center line of the excavation is determined as well as the wellpoint pumping rate Q. The depth Z_a is important in the assessment of the efficiency of the dewatering system. If the free surface is below the bottom of the excavation, the performance of the dewatering system is satisfactory. If it is above the bottom of the excavation, the dewatering system is failed and flooding occurs in the excavation.

RESULTS AND DISCUSSION

In order to verify the accuracy of the designed finite element model, Somerville equations (Equations 2 and 3) are applied at the case when the soil is isotropic and homogeneous ($k_1 = k_2$). The values of wellpoint pumping rate Q (m^3/s per meter run) and the height of water table at the mid-distance between two wellpoints h_D are obtained. A summary of the results is shown in Table 1. An excellent agreement is obtained between both methods for calculating h_D and the discrepancy is less than 2 %. Meanwhile, a noticeable difference between both methods for calculating Q is obtained. This is attributed to the fact that the finite element method is an approximate method and the solution to a given problem can be refined by the use of a mesh comprising more elements, and the use of a finer mesh could lead to a more exact solution. However, the results of the finite elements at least serve as a basis for comparison.

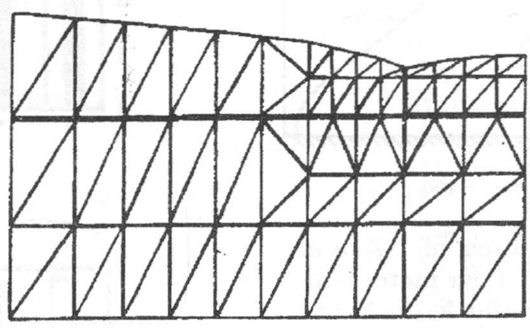

Figure 4 The finite element mesh

Table 1 A comparison between the results of the finite element and the Somerville equations

Finite element analysis		Somerville equations (Eqs. 2 and 3)	
Q (m^2/s/m)	h_D (m)	Q (m^2/s/m)	h_D (m)
5.9 × 10^{-5}	35.15	7.28 × 10^{-5}	35.63

Figures 5 and 6 show the equipotential lines produced by the finite element analysis for the cases $k_2 = k_1$ and $k_2 = 400\ k_1$, respectively. It can be seen that the presence of high permeable lens has a great influence on the distribution of the equipotential lines, and they become closer to others near the wellpoint. Therefore, more pumping rate from the wellpoint is expected compared to the homogeneous case ($k_2 = k_1$). It can also be seen that there is a local rise in the level of the free surface underneath the excavation due to the presence of the high permeable lens.

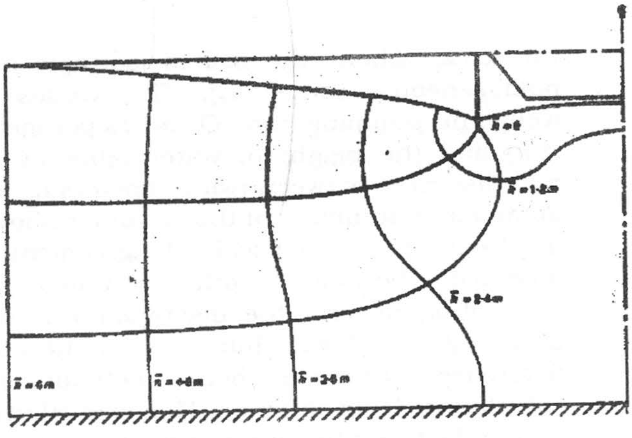

Figure 5 Equipotential lines for $K_2/K_1 = 1$ (no lenses)

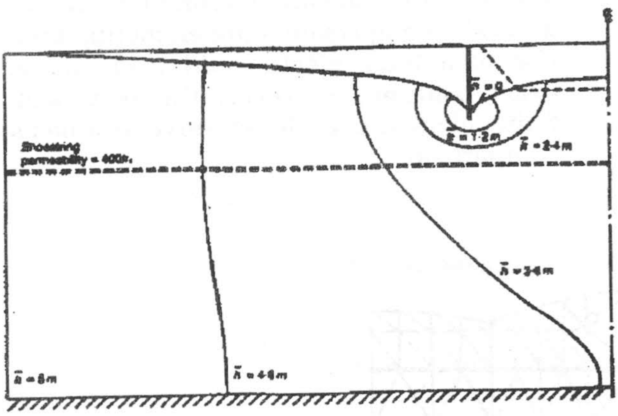

Figure 6 Equipotential lines for $K_2/K_1 = 400$

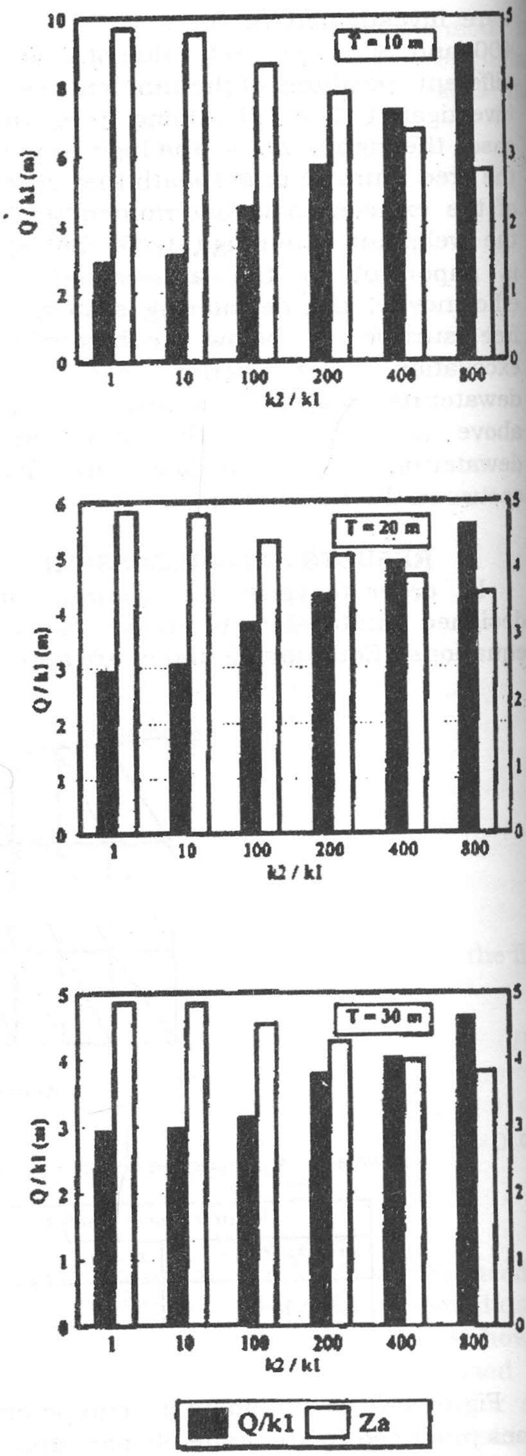

Figure 7 Effect of lenses permeability coefficient and locations on the pumping rate and dewatering depth

Figure 7 shows the values of Z_a and pumping rate Q/k_1 (in m^3/s per meter run, per m/s permeability) for ratios k_2/k_1 in the range 1 to 800 at T = 10, 20 and 30 m. It can be noticed that as the permeability of thin lens increase, the value of Z_a decrease. Accordingly, the elevation of the water table at the center line of the excavation rises. Meanwhile, the yield of the wellpoint system Q/k_1 increases rapidly. For instance, at $k_2/k_1 = 1$ and T = 10 m, Z_a equal 4.85 m which is bigger than the excavation depth (4 m). Thus, the dewatering system is working satisfactorily. Meanwhile, at $k_2/k_1 = 200$ and T = 10 m, the depth Z_a equal 3.89 m which means that the free surface is higher than the bottom of excavation and an instability of the excavation bottom is occurred.

A comparison between the three drawings in Figure 5, at a certain value of k_2/k_1, shows that the increase of position of the thin lens T causes an increase to Z_a and a decrease to the values of Q. Accordingly, the efficiency of the dewatering system is improved. This is because the source of recharge (the thin lens) is moved far from the bottom of the excavation.

CONCLUSIONS

The presence of high permeability lenses, which might pass undetected during site investigation, can result in an unsatisfactory performance of a wellpoint dewatering system which would have been adequate if the soil is homogeneous. The analysis indicates that the efficiency of the wellpoint dewatering system decreases as the permeability coefficient of the lens increases Meanwhile, the efficiency of the system is improved when the thin lens is moved far from the bottom of the excavation.

NOMENCLATURE

$\{F\}$= the global nodal force vector.
h_D= height of water table at the mid-distance between two wellpoints.
h_o= height of water table in wellpoints
h_w= drawdown of the wellpoint.
H_o= depth of impermeable layer below original water level.
k_1= soil coefficient of permeability.
k_2= permeability coefficient of lens.
$[K]$= the global stiffness matrix.
Q_s= total discharge from a pair of wellpoints.
Q= wellpoint pumping rate.
R_o= steady state distance of influence.
s= distance between the bottom of wellpoint and the impervious layer.
T= depth of thin lens below ground level.
x= length of excavation.
z= elevation head.
Z_a= depth of the highest point on the free surface underneath the center line of the excavation.
ϕ= total or potential head.
$\{\Phi\}$= the global vector of unknown head.

REFERENCES

1. S.H. Somerville, "Control of Ground-water for Temporary Works", CIRIA, Report 113, London, U.K., (1986).
2. J. P. Power, "Construction Dewatering, John Wiley and Sons, (1981).
3. G.A. Leonard, "Foundation Engineering, McGraw-Hill, pp. 284-288, (1962).
4. O.C. Zienkiweicz, "The Finite Element Method", McGraw-Hill, U. K. (1977),
5. J. Bear and A. Verruijt, "Modeling Groundwater Flow and Pollution", D. Reidel Publ. company, The Netherlands, (1987).
6. H.M. Moghazi, "A study of Pumping from a Partially Penetrating Well in an Anisotropic Unconfined Aquifer", Alexandria Engineering Journal, Vol. 31, No. 2, pp.C443 - 449(1992).
7. H.M. Moghazi and A.E. Hassan, "Seepage Surface in Earth Dams, Alexandria Engineering Journal, Vol. 35, No. 3, pp. C131 – 137, (1996).
8. E. Hinton and D. R. J. Owen, "An Introduction to Finite Element Computations", Pineridge Press Ltd., Swansea, U. K., (1979).
9. R.L. Taylor and C.B, Brown, "Darcy Flow Solution with a Free Surface", ASCE, Vol. 93, No. HY2, pp. 25 - 33, (1967).

Received November 25, 1998
Accepted April 6, 1999

تأثر كفاءة نظم تخفيض الماء الجوفي باستخدام الآبار الأبرية نتيجة وجود طبقات عدسية عالية النفاذية

حسام الدين محمد مراد مغازي
قسم هندسة الري والهيدروليكا - جامعة الإسكندرية

ملخص البحث

في كثير من الأحيان تتواجد طبقات عدسية عالية النفاذية ذات سمك صغير أسفل مواقع الحفر المختلفة. وقد استنتجت المعادلات المستعملة في تصميم نظم الآبار الأبرية على أساس أن التربة متجانسة دون التطرق لتأثير مثل هذه الطبقات على كفاءة استخدام هذه النظم. ولهذا تم إعداد نموذج رياضي باستخدام طريقة العناصر المحدودة لدراسة تأثير وجود مثل هذه الطبقات على كفاءة نظم تخفيض الماء الجوفي بالاعتماد على الآبار الأبرية. وتتضمن الدراسة تأثير هذه الطبقة على كل من معدل الضخ من هذه الآبار وعلى موقع السطح الحر للماء الجوفي أسفل موقع الحفر وهو مقياس لكفاءة نظام تخفيض مستوى الماء الجوفي في الموقع. وبينت النتائج أن وجود هذه الطبقات العدسية يمكن أن يسبب أداء سيئ للآبار الأبرية مقارنة بأدائها الجيد في حالة تربة متجانسة. وتبين أيضا أن كفاءة هذه النظم تتناقص بزيادة نفاذية الطبقات العدسية، في حين أن كفاءتها تتحسن كلما بعدت هذه الطبقات إلى أسفل بعيدا عن قاع الحفر.