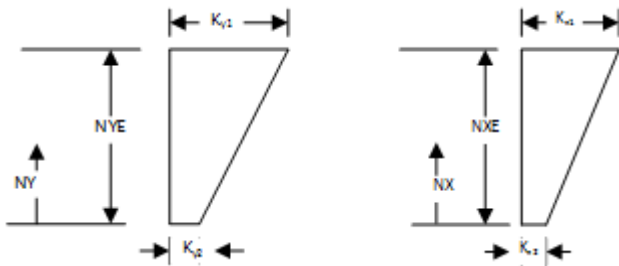


permeability of soil is considered isotropic and homogeneous and the excess pore pressures are recorded at different location from the centerline of the mesh, X/H_h . The second case considered the permeability of soil as anisotropic parameter and the excess pore pressures are recorded at two locations from the centerline of the mesh $X/H_h = 0$ and $X/H_h = 0.4$.

Figure (4) shows the effects of factor (X/H_h) on the average degree of consolidation for values (0, 0.2, 0.4, 0.6, 0.8). It shows that the average degree of consolidation increases with the increasing of (X/H_h). The increase of (X/H_h) means the region that the average degree of consolidation is calculated close to the drainage face. Figure (5) shows the effect of anisotropic ratio of permeability on the average degree of consolidation for different ratio of X/H_h (0, and 0.4), and different ratio of anisotropic ratio of permeability (1, 4, 6, 10). The average degree of consolidation increases at anisotropic ratio of permeability greater than one. Also increase of X/H_h will increase the average degree of consolidation.



$$K_{NY} = k_{y1} - (NY(k_{y1} - k_{y2}) / NYE) \quad K_{NX} = k_{x1} - (NX(k_{x1} - k_{x2}) / NXE)$$

Figure 3: Linear variation of permeability

5. Effect of Non Homogeneous Permeability Ratio

The results of the finite element program for all cases studied are presented as average degree of consolidation, U_{av} . It can be computed at any location in the mesh by the following formula ($U_{av} = 1 - u_e / u_o$) where u_e is the excess pore water pressure and u_o is the initial pore water pressure.

For the case of non-homogeneous permeability ratio in y direction $k_{y1}/k_{y2} = 8$ and anisotropic permeability ratio $k_{x1}/k_{y1} > 1$, when the anisotropic permeability ratio increases from 4 to 10, keeping constant value of non-homogeneous permeability ratio, the average degree of consolidation increases from 0.7 to 0.92 (Table 1). The increase in U_{av} is due to the increase in anisotropic permeability ratio.

Effect of the factor (X/H_h) at which the average degree of consolidation was calculated are also presented in Table 1. Two cases are discussed the first is for U_{av} computed at $X/H_h = 0$ and the second is for U_{av} computed at $X/H_h = 0.4$. The U_{av} calculated at $X/H_h = 0.4$ is greater than U_{av} calculated at $X/H_h = 0$ because this region is close to the right face of the mesh which is idealized as a drainage face in the presented problem.

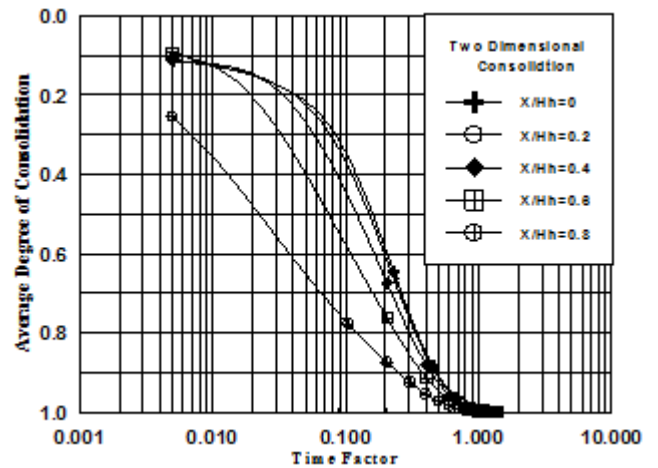


Figure 4: average degree of consolidation at different location X/H_h for homogeneous and isotropic soil.

Table 1: The effect of the anisotropic ratio of permeability and distance ratio X/H_h on the average degree of consolidation

H_v/H_h	K_x/K_y	X/H_h	T_v	K_{y1}/K_{y2}	U_{av}
1	10	0	0.03	8	0.5
1	10	0.4	0.03	8	0.6
1	4	0	0.1	8	0.7
1	10	0	0.1	8	0.92

For the case of non-homogeneous permeability in two directions together with the anisotropic permeability the U_{av} increases due to anisotropic of permeability of soil. With high permeability ratio the U_{av} decreases because the high permeability is concentrated close to the impervious face.

The high ratio of non-homogeneous permeability decreases the average degree of consolidation (Table 2) because the high permeability in x direction and y direction are close to the impervious side of the mesh.

Table 2: show the effect of the non-homogeneity in two direction and the distance ratio X/H_h on the average degree of consolidation

H_v/H_h	K_x/K_y	X/H_h	T_v	$K_{y1}/K_{y2}, K_{x1}/K_{x2}$	U_{av}
1	10	0	0.1	1.1	0.94
1	10	0	0.1	8.8	0.58
1	10	0.4	0.1	8.8	0.63

Table 2 also shows the result of average degree of consolidation for the case of two dimensional consolidation for soil with anisotropic permeability and non homogeneous permeability in x and y direction. The average degree of consolidation is calculated at two location represented by X/H_h . It is shown that the average degree of consolidation increases as the location closes to the face of drainage.

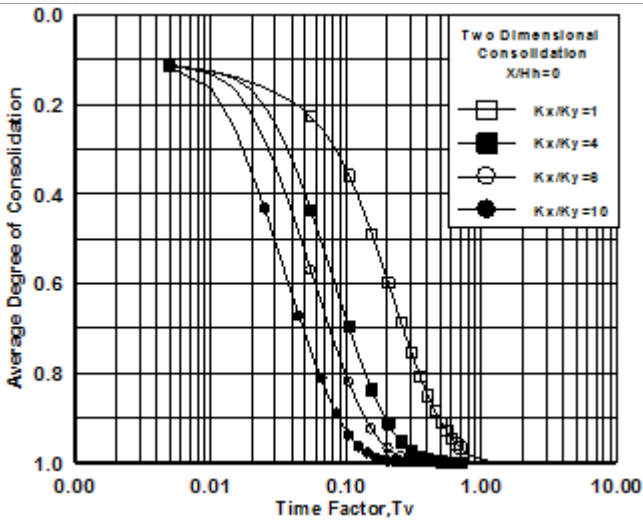


Figure 5: average degree of consolidation at $X/H_h=0$ for different anisotropic permeability ratio

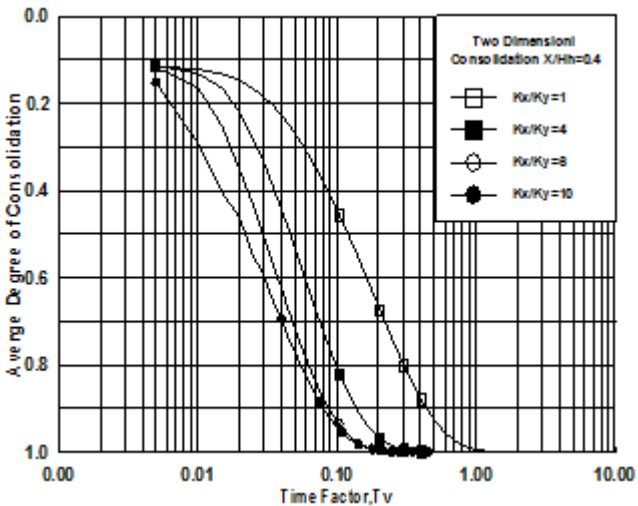


Figure 6: average degree of consolidation at $X/H_h=0.4$ for different anisotropic permeability ratio

6. Effect of Anisotropic and Homogeneous Permeability

The study also considered rectangular mesh of dimensions H_v and $H_h = 2H_v$ (Figure 7). Three cases are studied, the first case is for soil with isotropic permeability and non-homogeneous permeability in y or/and in x direction where the U_{av} is calculated at $X/H_h = 0.4$. The effect of anisotropic permeability on the U_{av} are studied in the other two cases by using anisotropic permeability ratio of $k_{x1}/k_{y1} = 4$ and 10. The non-homogeneous and anisotropic permeability reflects the nature of assumed soils which approximately represent real soil.

Figure 8a shows the result of U_{av} for case of soil with isotropic and non-homogeneous permeability in y direction and homogeneous permeability in x direction.

Figure 8b shows the results of U_{av} for the case of soil with isotropic and non-homogeneous permeability in x and y direction. From the two Figures, it is found the effect of non-homogeneous permeability ratio in x-direction has slightly effect on U_{av} . It is attributed to that the increase of ratio of

non-homogeneous permeability in x-direction means increase in permeability in the region that is far from the drainage face of the soil while the region close to the drainage face still has the same value of permeability.

Figure 9a and Figure 10a show the U_{av} versus time factor, T_v , for the same previous case of soil with non-homogeneous permeability in y direction and homogenous permeability in x direction but for anisotropic permeability $k_{x1}/k_{y1} = 4$ and $k_{x1}/k_{y1} = 10$. The results of U_{av} are approximately the same. The anisotropic permeability has no effect on the U_{av} .

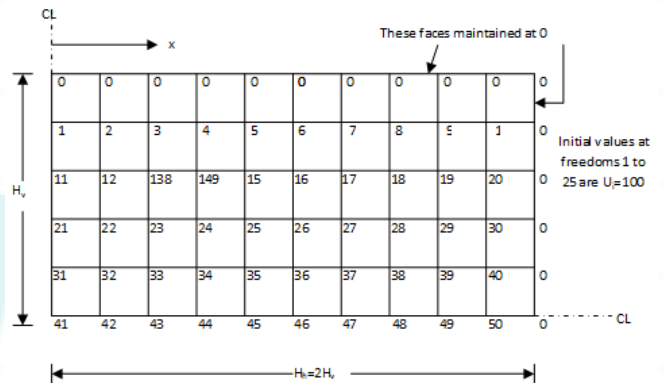


Figure 7: Grid of the studied problem

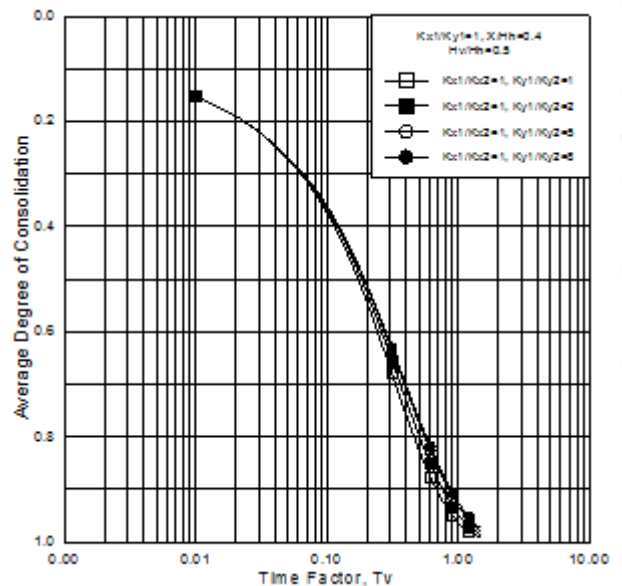


Figure 8a: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with isotropic permeability, $k_{x1}/k_{y1} = 1$, homogeneous permeability in x direction and non-homogeneous permeability in y direction

This may be attributed to that the high permeability is close to the impervious face. Figure 9b and Figure 10b show the result of U_{av} against T_v for soil with non-homogeneous permeability in both x and y direction and with same ratio of anisotropic permeability. It is obvious that the U_{av} increases as non-homogeneous permeability increases from $k_{x1}/k_{x2} = 1$ to $k_{x1}/k_{x2} = 8$.

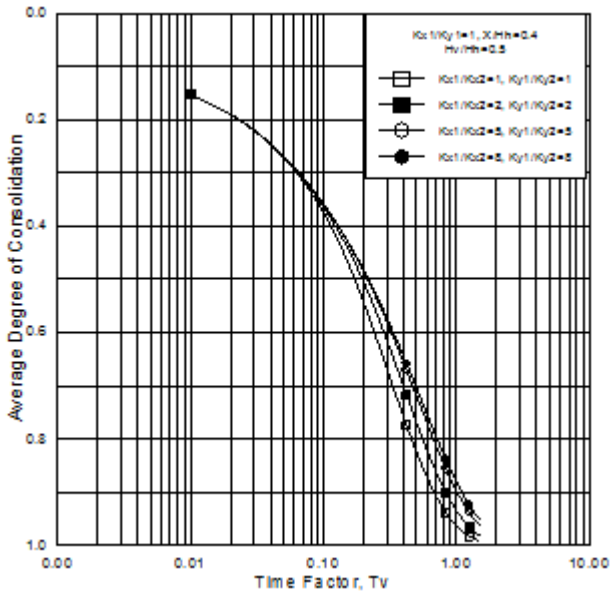


Figure 8b: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with isotropic permeability, $k_{x1}/k_{y1} = 0$, non-homogeneous permeability in y direction and non-homogeneous permeability in x direction

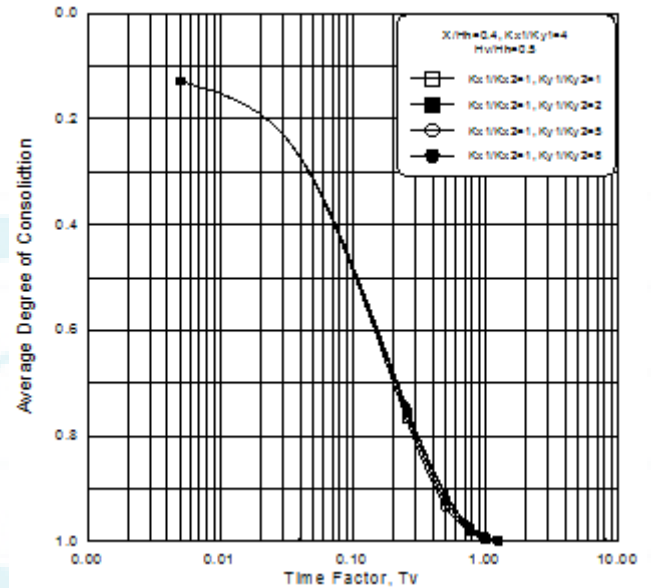


Figure 9b: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with anisotropic permeability, $k_{x1}/k_{y1} = 4$, non-homogeneous permeability in y direction and non-homogeneous permeability in x direction

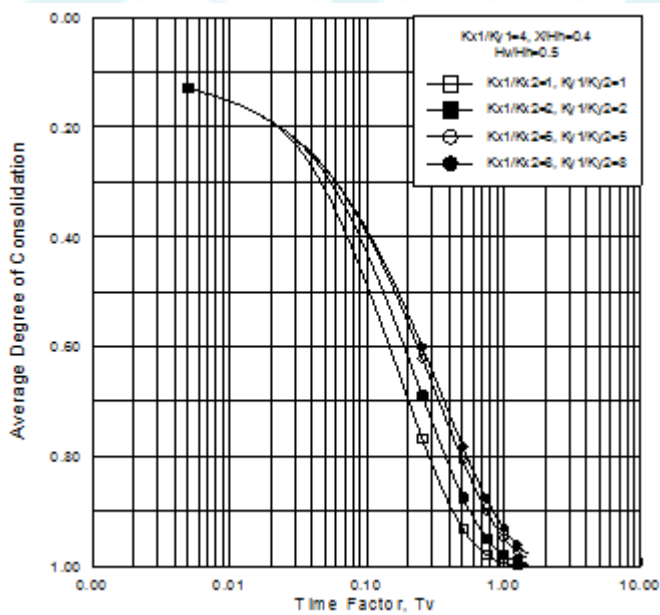


Figure 9a: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with anisotropic permeability, $k_{x1}/k_{y1} = 4$, non-homogeneous permeability in y direction and homogeneous permeability in x direction

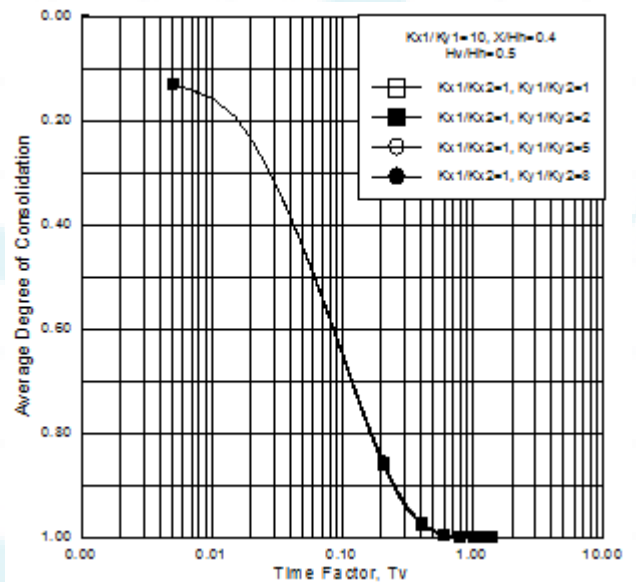


Figure 10a: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with anisotropic permeability, $k_{x1}/k_{y1} = 10$, non-homogeneous permeability in y direction and homogeneous permeability in x direction

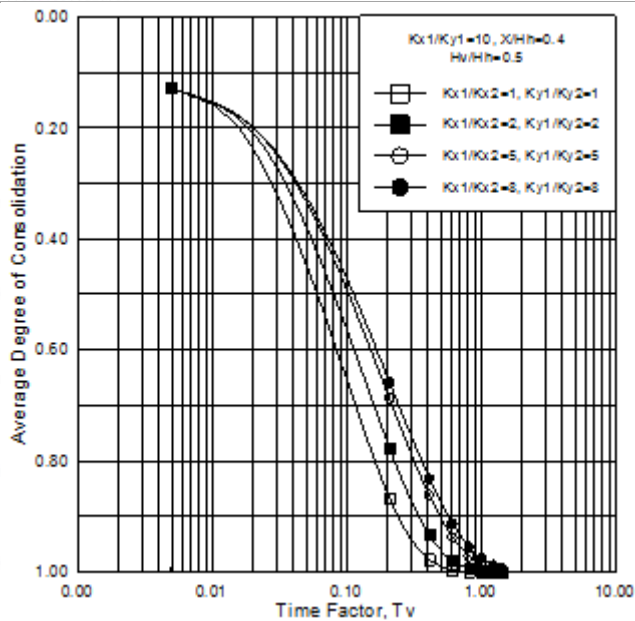


Figure 10b: Average degree of consolidation, U_{av} , versus time factor, T_v , for soil with anisotropic permeability $k_{x1}/k_{y1} = 10$, non-homogeneous permeability in y direction and non-homogeneous permeability in x direction

7. Conclusion

In this study a computer program which depends on the uncoupled solution using finite element method has been used to solve problem of two-dimensional consolidation settlement. This computer program is a good tool to study the non-homogeneous and anisotropic permeability effects on the average degree of consolidation. According to the study, the following conclusions are drawn:

1. It is concluded that the average degree of consolidation decreases with the decrease of permeability with depth "non-homogeneous permeability in y direction.
2. The soil layer of low permeability which located close to the drainage face reduces the average degree of consolidation.
3. The average degree of consolidation increases when the anisotropic permeability ratio increases more than one
4. Including real variation of permeability in the soil to compute the average degree of consolidation has to be depended on in design.

References

- [1] Terzaghi, K.,(1943) Theoretical Soil Mechanics, Wiley Publications, New York.
- [2] Rendulic L.,(1936), " Porenziffer and Porenwasserdruck in Tonen" mentioned by N. Foldin and B. Browns, In "Soft clay in engineering", 1981, Elsevier Scientific publishing Company.
- [3] Carillo, (1942), "Simple Two and Three Dimensional Cases in the Theory of Consolidation of Soils", J. Math. And Phys., No.1, P. 1-5.
- [4] Poskitt, T.,J.(1970) "Settlement Charts for An Isotropic Soil", Geotechnique, Vol.20, No.3, pp.325-330.

- [5] Zhu, G. and Yin, J-H, 2005. Solution charts for the consolidation of double soil layers. Canadian Geotechnical Journal, 42:949-956.
- [6] Abbasi, N., Rahimi, H., and Javadi, A. A. And Fakher, A. (2007) Finite difference approach for consolidation with variable compressibility and permeability. Computer and Geotechnics. 34(1), (2007), pp. 41-52.
- [7] Kang-He Xie, Xin-Yu Xie, Xiang Gao, Theory of one dimensional consolidation of two-layered soil with partially drained boundaries, Computers and Geotechnics, Volume 24, Issue 4, June 1999, Pages 265-278, ISSN 0266-352X.
- [8] Amiri S. N and Eamaely A. (2014) A realistic theory of soils consolidation" Journal of science and geotechnical engineering" Vol 4, no 1, 103-129.
- [9] Smith, I. M. and Griffiths, D.V. (1998) "Programming the Finite Element" Method third edition, Jon Wiley & Sons, England.
- [10] J Huang, DV Griffiths (2010) "One-dimensional consolidation theories for layered soil and coupled and uncoupled solutions by the finite-element method" Geotechnique, Volume 60. Issue 9 Pages 709-713
- [11] Carslaw, H.S., and Jaeger, J.C.(1959) "Conduction of Heat in Solids", 2 nd edn. Clarendon Press, Oxford