Estimation of Uplift Pressure Equation at Key Points under Floor of Hydraulic Structures

Mohammed Hamid Rasool, Laheab A. Al-Maliki, Sohaib Kareem Al-Mamoori & Nadhir Al-Ansari |

To cite this article: Mohammed Hamid Rasool, Laheab A. Al-Maliki, Sohaib Kareem Al-Mamoori & Nadhir Al-Ansari | (2021) Estimation of Uplift Pressure Equation at Key Points under Floor of Hydraulic Structures, Cogent Engineering, 8:1, 1917287, DOI: 10.1080/23311916.2021.1917287

To link to this article: https://doi.org/10.1080/23311916.2021.1917287

© 2021 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

Published online: 04 May 2021.

Submit your article to this journal

Article views: 311

View related articles

View Crossmark data
Estimation of Uplift Pressure Equation at Key Points under Floor of Hydraulic Structures

Mohammed Hamid Rasool¹, Laheab A. Al-Maliki², Sohaib Kareem Al-Mamoori³* and Nadhir Al-Ansari⁴

Abstract: Most of the hydraulic structures rest on an impervious foundation to reserve water at the upstream side. The water heads difference leads to water movement from the higher to the lower head through the porous soil layer beneath the foundation, generating an uplift pressure under the structure floor. In this study, a new method is presented to estimate the uplift pressures at key points by performing sub-surface flow analysis using the Analysis SYStem (ANSYS) software. Then a statistical analysis to validate the proposed equations is conducted using the SPSS software. The case study for this research is a barrage in Kufa city-Iraq. The used data to implement this study was water levels, soil permeability, and length of imperious foundation. The obtained results show good outcomes from using the proposed method to develop uplift pressure equations. The comparison of the current study results with Khosla’s equation showed good agreement where the coefficient of determination (R²) and the standard error of estimation (SEE) for the equations were between (99.9–97.8) and (0.024–0.11), respectively.

Subjects: Statistical Theory & Methods; Water Science; Hydraulic Engineering

Keywords: seepage; statistical; uplift pressures; ANSYS; f

1. Introduction
Most hydraulic structures reserved water upstream of structures. To achieve structures’ equilibrium, water transmission (seepage) will occur from maximum to minimum head passing through the soil, generating three types of forces: uplift pressure under improvis floor, seepage discharge, and exit gradient. Uplift pressure reduces the share resistance between soil and foundation, causing a decrease in structures’ stability against sliding or overturning. Increasing the seepage
discharge at the end of the foundation causes soil particles’ movement and accelerates piping and soil erosion. The exit gradient is a criterion for designing hydraulic structures to determine their safety against the piping phenomenon (Khalili Shayan & Amiri-Tokaldany, 2015).

To solve this problem, a sheet pile is installed under the hydraulic structures with embedded vertical length. The uplift pressure under hydraulic structures with one or more vertical sheet piles was investigated using many scholars’ approaches like Khosla (1936) (AN Khosla et al., 1936), Harr (1962), Leliavsky (1955), Karl et al. (1967), and others. However, limited literature is available for seepage through a previous medium beneath a hydraulic structure with an inclined sheet pile. Bligh (1910) and E. W. Lane (1935) were the first who studied the seepage effect by estimating the length of creep for the flow passing under hydraulic structures (creep length is the line which touches the structural floor) and computed that path by summation of the vertical and horizontal distances. In the end, Bligh and Lane provided a coefficient to calculate the minimum length of the creep path depending on the soil type and water depth. However, this way is minimal to design the foundation of hydraulic structures (Bligh, 1910; E. W. Lane, 1935).

Khosla (1999) presented a method to estimate the uplift pressure under hydraulic structures based on solving the Laplace equation as a predominant equation in steady conditions (Ashok Khosla, 1999).

\[ \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0. \]

Even though this equation can solve complex problems, it is hard to apply when the seepage flow is changed by a cut-off wall and will result in complicated integrals (Harr, 1962). Scholars studied two cases of finite-depth seepage: with and without cut-off to introduce analytical solutions (Harr, 1962; Leliavsky, 1955; Polubarinova-Koch, 2015). Fil’chakov (1959) analytically studied the finite-depth seepage using weirs with cut-offs for several schemes (Fil’chakov, 1959). Abedi Koupaei (1991) estimated the uplift pressure distribution using four different methods and compared the results to find that the uplift pressures estimated by using Bligh and Lane equations are less than both Khosla and finite difference methods (FDMs) (Abedi Koupaei, 1991). Griffiths & Fenton (1997) modeled the 3D steady seepage using a combination of the finite element method (FEM) (Emmanuel, Oladipo, & Olabode) and random fields generating techniques (Griffiths & Fenton, 1997). Sedghi-Asl et al. (2005) studied the cut-off wall position effect on seepage and the flow velocity under hydraulic structures. According to their results, the best cut-off positions were at the upstream and downstream ends, respectively (Říha, 2020; SedghiSedghi-Asl et al., 2005). Ahmed and Bazaraa (2009) used FEM to investigate the 3D seepage path under and around hydraulic structures. They aimed to reduce the seepage losses and design a stable hydraulic

![Figure 1. Comparison of the FEM and experimental results (Rasool, 2018).](https://doi.org/10.1080/23311916.2021.1917287)
structure by comparing 3D with 2D analyses for calculating the exit gradient (Ahmed & Bazaraa, 2009). Hillo (1993) used FEM to analyze seepage under hydraulic structures for different models to obtain pressure distribution under foundation and exit gradient variations along the downstream bed. Finite element results were obtained for seepage around a single sheet pile and two sheet piles by Hillo and Lane (Hillo, 1993; E. W. J. T. o. A. Lane, 1935). Ahmed & Elleboudy (2010) used the finite element to study the effect of increasing the length of the sheet pile more than the length of the hydraulic structures on uplift pressure and exit gradient. The authors found that increasing the length has no significant influence on uplift pressure and exit gradient. Furthermore, the sheet pile reduces the exit gradient and increases the uplift pressure (Ahmed & Elleboudy, 2010).

Obead (2013) used a computational method to simulate the seepage phenomenon and estimate the uplift pressure at a key point. He studied sheet piles location and inclination angle effect on seepage phenomena under the dam's impervious floor (Obead, 2013). Novak (2014) developed an equation (Khosla equations) to measure the uplift pressure at the key point. However, using that equation must impose no slope of the floor, one sheet pile, and neglect its thickness. Then, they suggested correction factors for thickness, slope, and influence mutual interference (Novak et al., 2014). Nassralla et al. (2016) studied the effect of using two layers of soil on seepage properties with sheet pile experimentally and discussed with a numerical computer program (Geo—Studio SEEP/W model). The results showed that the uplift pressures decrease if the upstream pile was less than half the soil layer depth. A comparison with numerical results yielded an excellent agreement (Nassralla, Raba, & Technology, 2016). Jamel (2017) used three parameters upstream sheet piles, downstream sheet piles, and permeability of two layers to study their effect on seepage properties (uplift pressure and exit gradient) by using a computer program (Geo—Studio SEEP/W model). He then proposed empirical equations to calculate seepage discharge, uplift pressures, and exit gradient by a statistics software program (SPSS) (Jamel, 2017).

Rasool (2018) studied the possibility of using the FEM to simulate uplift pressure under hydraulic structures. The other used several sheet piles for many depths and locations to study their effect on uplift pressure. The results showed good agreement between FEM and experimental results, as shown in Figure 1 (Rasool, 2018).

In this study, equations will be developed based on the finite element analysis ANSYS results to calculate the required uplift pressure at key points of a hydraulic structure foundation. The
The selected hydraulic structure is Kufa barrage that has sheet piles at the upstream, middle, downstream sides (Figure 2). The developed equations will provide information on the values of uplift...
pressure at key points of hydraulic structures. Also, verification of these results is performed using both Khosla's method and finite element results.

2. Methodology

2.1. Analysis System (ANSYS)
ANSYS (version 15.0) is a finite element analysis software used in engineering simulation. The software creates simulated computer models of structures, machine components to simulate strength, toughness, temperature distribution, fluid flow, and other attributes. ANSYS has many elements to model structures and analyzes them for suitable loads (Al-Deley et al., 2006; Kamanbedast & Delvari, 2012; Stolarski et al., 2018). 2D Element (plan 77) (eight-node-one degree of a free dome) was adopted to simulate the soil layers under structures and the size of elements.
used to achieve the best results (Dekhn, 2008; Rasool, 2018). The permeability coefficient of soil is hydraulic conductivity \( (K_{xx} = K_{yy}) \) homogenize (Hosseinzadeh Asl et al., 2020; Singh et al., 2019). Finally, the boundary conditions are the head of water upstream and downstream.

### 2.2. Statistical Package for the Social Sciences (SPSS)

The SPSS is a popular package of computer software. Nonlinear regression is one of the SPSS software methods, which has been used to develop the equations (Yin et al., 2019). This method is used to estimate the uplift pressure equations at key points under hydraulic structures.

The coefficient of determination \( (R^2) \) (Eq. 2), standard error of estimation (SEE) (Eq.3), and the mean absolute percentage error (MAPE) are the used criteria to show the percentage error for the suggested equations. They are calculated by Eqs. 2–4 as follows:
\[ R^2 = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2 - (\sum x)^2)][n(\sum y^2 - (\sum y)^2)]}} \]  

\[ SEE = \sqrt{\frac{\sum(Y - \hat{Y})^2}{N}} \]  

\[ MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{x - y}{y} \right| \times 100 \]  

where

- \( y \) = observed values
\[ (Y - Y')^2 = \text{sum of squared deviations.} \]
3. Results and discussion

3.1. Relations between the variables

Figure 3 shows the relationship between the head of water (H) m and the percentage of pressure at key points under hydraulic structures (ØE₁, ØC₁, ØD₁, ØE₂, ØD₂, ØC₂, ØE₃, ØD₃, ØC₃). The value of ØE₁ is the same as the value of pressure at the structure beginning due to its location at the first point upstream. Also, ØC₃ value is equal to the pressure downstream of the structure because of its location at the end. But the other point values are affected by the proportion of the water head; if the water head increased (50%), the average percentage of pressure at key points is reduced by 10.55%.

The soil permeability (hydraulic conductivity) causes seepage phenomena, so that we used isotropic homogenous soil K. Figure 4 shows the relationship between the uplift pressure at the key points with soil permeability. This factor is small compared to the value of pressure because it is directly on the seepage amount.

The percentage of uplift pressure is affected by the impervious foundation length L. Figure 5 shows the result of U.P. for pile 1 is increased 31% by increasing L from 40 to 160 m. Also, at 7.5% ration the difference between the result of U.P. for pile 2 with increase in L. But the values of U.P. for pile 3 is reduced by 45% with an increase in L.

Additionally, the uplift pressure is reduced by 33% with an increase depth of pile (d₁). But the increased depth of pile (d₂) leads to an increase in the pressure at upstream 12% because the flux will be specific between the wall of the sheet pile and reduces the pressure downstream. The depth of pile (d₃) increases the uplift pressure by 34%, furthermore, this case effects on exit gradient (Rasool, 2018).

| Table 2. Limits of used variables in the proposed equation |
|-----------------------------------------------------------|
| No. | Sample | Unit | Limit       |
|-----|--------|------|-------------|
| 1   | L      | m    | 25-160      |
| 2   | H₁     | m    | 2-12        |
| 3   | H₂     | m    | 0.5         |
| 4   | X      | m    | 2-38        |
| 5   | d₁     | m    | 2-12        |
| 6   | d₂     | m    | 2-12        |
| 7   | d₃     | m    | 2-12        |
3.2. Equations development

The results presented from ANSYS analysis for uplift pressure at the key points were used to develop equations for calculating the pressure percentage. Statistical program (SPSS) helps estimate the equation parameters.

The suggested form of the equation is ($c =$

\[ d_1^\alpha + d_2^\beta + d_3^\gamma + H^\delta + L^\epsilon + X^\zeta + m \]

Figure 14. Values of error for the measured point.

(a) The percentage of uplift pressure at point C1 was calculated from Eq. (5). $R^2$ and SEE for the proposed equation were 0.999 and 0.038, respectively. Figure 6 compares the actual values and predicted values.

\[ C_1 = \frac{d_1^{0.0134} + d_2^{0.0594} + H^{0.9705} + L^{0.1535} + 0.5357}{x^{0.0178} + \sigma_1^{2.283}} \]

Figure 15. Values of $R^2$ for the equations.

(a) The percentage of uplift pressure at point D1 was calculated from Eq. 6. $R^2$ and SEE for the proposed equation were 0.999 and 0.029, respectively. Figure 7 shows compression between the actual values and predicted values.
\[
D_1 = \frac{d_1^{0.0245} + d_4^{0.0446} + H_0^{0.9773} + L_0^{1.12169} + 0.5853}{x^{0.00502} + d_1^{0.1712}}
\]  
(8)

(a) The percentage of uplift pressure at point \(E_2\) was calculated from Eq. 7. \(R^2\) and SEE for the proposed equation were 0.984 and 0.11, respectively. Figure 8 shows compression between the actual values and predicted values.

\[
E_2 = \frac{d_1^{0.1045} + d_4^{0.1204} + H_0^{0.9582} + 0.9681}{L_0^{0.02952} + x^{0.1222} + d_1^{0.1596}}
\]  
(9)

(a) The percentage of uplift pressure at point \(C_2\) was calculated from Eq. 8. \(R^2\) and SEE for the proposed equation were 0.982 and 0.11, respectively. Figure 9 shows compression between the actual values and predicted values.

\[
D_2 = \frac{d_1^{0.0256} + d_4^{0.1383} + H_0^{0.9525} + 0.9335}{L_0^{0.003063} + x^{0.1332} + d_1^{0.1527}}
\]  
(10)

(a) The percentage of uplift pressure at point \(C_2\) was calculated from Eq. 9. \(R^2\) and SEE for the proposed equation were 0.978 and 0.11, respectively. Figure 10 compares the actual values and predicted values.

\[
C_2 = \frac{d_4^{0.175} + H_0^{0.0477} + 0.8}{d_4^{0.094} + x^{0.1396} + d_1^{0.1525}}
\]  
(11)

(a) The percentage of uplift pressure at point \(E_3\) was calculated from Eq. 10. \(R^2\) and SEE for the proposed equation were 0.996 and 0.034, respectively. Figure 11 compares the actual values and predicted values.

\[
E_3 = \frac{d_4^{0.3371} + H_0^{0.8713} + 1.458}{d_4^{0.04822} + L_0^{0.129} + x^{0.01287} + d_1^{0.1324}}
\]  
(12)

(a) The percentage of uplift pressure at point \(D_3\) was calculated from Eq. 11. \(R^2\) and SEE for the proposed equation were 0.997 and 0.024, respectively. Figure 12 compares the actual values and predicted values.

\[
D_3 = \frac{d_4^{0.3022} + H_0^{0.8305} + 1.3107}{d_4^{0.0453} + L_0^{0.1162} + x^{0.00624} + d_1^{0.126}}
\]  
(13)

Also, the limitations of these equations are listed in Table 2.

4. Validation of the suggested equations

Data from a further six measurements were used to verify equations’ accuracy (5–11) calibration with Novak 2014. Figure 13 shows the pressure for points under hydraulic structures. These values represent the results of Khosla’s method, the suggested equations, and ANSYS analysis. Figure 14 presents the difference values for two statistical criteria (SEE and) for Eqs. 3 and 4, respectively, and the coefficient of determination \(R^2\) for Eq. 2 is presented in Figure 15.

Also, the average difference between values is less than 5% for points 1–6, so the developed equations can be used to estimate the percentage pressure at key points for hydraulic structures.
5. Conclusion
In this study, the upstream blanket and the sheet pile effects on reducing uplift pressure were investigated using FEM data. It is found that the FEM can be used as a useful tool for estimating the uplift pressure for a wide range of conditions (Rasool, 2018). Moreover, data analysis revealed that the sheet pile’s best position is at the upstream end to reduce uplift pressure. The results agree with Sedghi-Asl et al. (2005), Khalil Shayan & Amiri-Tokaldany (2015), and AL-Musawi et al. (2006), who also found the best location of the pile to reduce the uplift pressure at the upstream end. At the same time, utilizing SPSS for analysis can be helpful in the suggested equations for calculating the U.P. at key points of each pile as follows:

- The pressure at the upstream sheet pile increased by increasing \( d_1 \), \( d_2 \), \( H \), and \( L \), while reduced by increasing \( d_2 \).
- The pressure at point \( E_2 \) was increased by increasing \( d_1 \), \( d_3 \), and \( H \) and reduced by reducing \( L \), \( X \), and \( d_1 \) due to the mutual effect between piles 1 and 2.
- The pressure at point \( D_2 \) was increased by increasing \( d_2 \), \( d_3 \), and \( H \) and reduced by reducing \( X \) and \( d_1 \).
- The pressure at point \( C_2 \) was increased by increasing \( d_3 \), \( L \), and \( H \) and reduced by increasing \( d_2 \), \( X \), and \( d_1 \).
- The pressures at points \( E_3 \) and \( D_3 \) were increased by increasing \( d_3 \) and \( H \) and reduced by increasing \( d_2 \), \( L \), \( X \), and \( d_1 \).

It may be evident that the effect of variables \( x \) (1.44 and 1.79%) and \( L \) (0.43%) were small for all sheet piles and can be neglected.

Finally, despite the progress made in this paper, however, there are limitations to using general applications, so further research is needed. Also, only one layer of soil material was selected as a porous media under the foundation of the hydraulic structures, while a wide range of materials may be available in prototype situations.

Funding
The authors received no direct funding for this research.

Author details
Mohammed Hamid Rasool1
ORCID ID: http://orcid.org/0000-0001-8512-5256

Laheeb A. Al-Maliki2
ORCID ID: http://orcid.org/0000-0002-7819-797X

Sohab Kareem Al-Mamoori3
E-mail: sohab.almamoori@uokufa.edu.iq
ORCID ID: http://orcid.org/0000-0001-8941-9550

Nadhir Al-Ansari4
1 Department of Management of Water Resources, Faculty of Water Resources Engineering, University of Al-Qasim Green, Babylon, Iraq.
2 Department of Hydraulic Engineering Structures, Faculty of Water Resources Engineering, University of Al-Qasim Green, Babylon, Iraq.
3 Department of Environmental Planning, Faculty of Physical Planning, University of Kufa, Najaf, Iraq.
4 Department of Civil, Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden.

Abbreviations
ANSYS: Analysis SYstem software
SPSS: Statistical Package for the Social Sciences
SEE: standard error of estimation
MASE: the mean absolute percentage error (%)
\( R^2 \): the coefficient of determination
\( K_{h} \): horizontal permeability coefficient
\( K_{v} \): vertical permeability coefficient
\( L \): total length of the impervious floor; m
\( d_1 \): sheet pile at upstream; m
\( H_1 \): headwater upstream; m
\( d_2 \): sheet pile at intermediate; m
\( H_2 \): headwater downstream; m
\( d_3 \): sheet pile at downstream; m

Citation information
Cite this article as: Estimation of Uplift Pressure Equation at Key Points under Floor of Hydraulic Structures, Mohammed Hamid Rasool, Laheeb A. Al-Maliki, Sohab Kareem Al-Mamoori & Nadhir Al-Ansari, Cogent Engineering (2021), 8: 1917287.

References
Abedi Koupaei, J. (1991). Investigation of effective elements on uplift pressure upon diversion dams by using finite difference. thesis for MSC (in Persian), University of Tarbiat Modarres
Ahmed, A. A., & Bazaraa, A. S. (2009). Three-dimensional analysis of seepage below and around hydraulic structures. Journal of Hydrologic Engineering, 14(3), 243-247. https://doi.org/10.1061/(ASCE)1084-0699 (2009)14:3(243)
Ahmed, A. A., & Elleboudy, A. M. (2010). Effect of sheetpile configuration on seepage beneath hydraulic structures. In Scour and Erosion (pp. 511–518)
Al-Deleywi, A. A., Shukur, A.-H. K., & AL-Musawi, E. W. H. (2006). Optimum design of control devices for safe seepage under hydraulic structures. Journal of Engineering and Sustainable Development, 10(1), 66–87. https://www.iasj.net/iasj/article/10146
Al-Musawi, W. H., Shukur, A.-H. K., & Al-Deley, A. A. (2006). Optimum design of control devices for safe seepage under hydraulic structures. Journal of Engineering and Sustainable Development, 10(1), 66–87.

Bligh, W. (1910). Dams, barrages and weirs on porous foundations. Engineering News, 64(26), 708–710.

Dekht, H. C. (2008). Analysis of Seepage Under Hydraulic Structures for Different Cases Using Finite Element Method. (Master Degree), University of Kufa, Fil'chakov, P. (1959). The theory of filtration beneath hydrotechnological structures. In Izd-vo Akademii nauk Ukrainskoi SSR Kiev.

Griffiths, D., & Fenton, G. A. (1997). Three-dimensional seepage through spatially random soil. Journal of Geotechnical and Geoenvironmental Engineering, 123(2), 153–160. https://doi.org/10.1061/(ASCE)1090-0241(1997)123:2(153)

Harr, M. (1962). Groundwater and Seepage, p 249 McGraw-Hill Book Co. In Inc. New York.

Hillo, A. (1993). Finite Elements for Seepage below Hydraulic Structure on Anisotropic Soil Foundation. M. Sc. Thesis, College of Engineering, University of Basrah.

Hosseinzadeh Asl, R., Salmasi, F., & Arvanaghi, H. (2020). Numerical investigation on geometric configurations affecting seepage from unlined earthen channels and the comparison with field measurements. Engineering Applications of Computational Fluid Mechanics, 14(1), 236–253. https://doi.org/10.1080/19942060.2019.1706639

Jamel, A. A. J. J. F. E. S. (2017). Effect of Two Sheet Piles in Double Soil Layers on Seepage Properties under Hydraulic Structure Using SEEP/W Program, 20(1), 194–205. https://www.nahje.com/index.php/main/article/view/86

Kamanbedast, A., & Delvari, A. J. W. A. S. J. (2012). Analysis of Earth Dam: Seepage and Stability Using Ansys and Geo-studio Software, 17(9), 1087–1094. http://www.idosi.org/.../4.pdf

Karl, T., Peck, R. B., & Mesri, G. (1967). Soil mechanics in engineering practice (3rd ed.), ed. Wiley.

Khalili Shayan, H., & Amir-Tokaldany, E. (2015). Effects of blanket, drains, and cut-off wall on reducing uplift pressure, seepage, and exit gradient under hydraulic structures. International Journal of Civil Engineering, 23(6), 486–500.https://doi.org/10.22068/IJCE.13.4.486

Khosla, A. (1999). Policy Matters, Newsletter of the IUCN Commission on Environmental, Economic and Social Policy (CEESP).

Khosla, A., Bose, N., & McKenzie, E. (1939). Design of weirs on pervious foundations. In: Publication.

Lane, E. W. (1935). Security from under seepage masonry dams on earth foundations. Transactions of ASCE, 100(1), 1234–1351. https://doi.org/10.1061/TACEAT.000655

Leiavsky, S. (1955). Irrigation and hydraulic design.

Nassralla, T., & Raboe, A. J. T. E. I. J. E. S. (2016). Technology. Seepage Characteristics under Hydraulic Structure Foundation (Supported by Sheet Pile) in Multi-Layers Soil, 18(4), 229–238. https://journals.ekb. eg/article_97121_s159559a1c2b-f71067f1306bbfd590f.pdf

Novak, P., Moffet, A., Nalluri, C., & Narayanan, R. (2014). Hydraulic structures. CRC Press.

Obad, I. H. J., & K. U. (2013). Effect of Position and Inclination Angle of Cut-off Wall on Seepage Control in the Foundation of Dam Structure, 11(4), 17–32. https://ki.uckerbaloa.edu.ig/article_82420.html

Polubarinova-Koch, P. I. (2015). Theory of ground water movement. Princeton University Press.

Rasool, M. H. J. K. O. E. (2018). Effect of Mutual Interference Piles on Seepage Properties under Hydraulic Structures 9(4), 273-285. https://ipdfs.semanticscholar.org/df39/39cbf2dc8776d4951af32c54f8900d3908ed.pdf.

Rıha, J. (2020). Groundwater Flow Problems and Their Modelling. In Assessment and Protection of Water Resources in the Czech Republic (pp. 175–199). Springer, Springer Water book series.

Sedghi-Asl, M., Rahimi, H., & Khaleghi, H. (2005). Effect of cut-off wall’s depth and situation on reducing seepage under hydraulic structures by using numerical method. Paper presented at the Fifth Iranian Hydraulic Conference, Kerman University, Ahvaz, Iran.

Singh, B., Sihag, P., Pandhiani, S. M., Debnath, S., & Gautam, S. J. I. O. H. E. (2019). Estimation of Permeability of Soil Using Easy Measured Soil Parameters: Assessing the Artificial Intelligence-based Models, 1–11. https://doi.org/10.1007/s00710-019-1574615

Stolarski, T., Nakasone, Y., & Yoshimoto, S. (2010). Engineering analysis with ANSYS software. Butterworth-Heinemann.

Yin, S., Xie, R., Wu, Z., Liu, J., & Ding, W. (2019). In situ stress heterogeneity in a highly developed strike-slip fault zone and its effect on the distribution of tight gases: A 3D finite element simulation study. Marine and Petroleum Geology, January, 99, 75–91. https://doi.org/10.1016/j.marpetgeo.2018.10.007
