Groundwater Seepage Modeling in the Basement of Building X and its Handling

Miftakhul Muadhomah, Dimas Arya Pratama, Garup Lambang Goro, Risman Risman, And Aiun Hayatu Rabinah

Civil Engineering Department,
State Polytechnic of Semarang, Semarang, Indonesia
garup.lambang.goro@polines.ac.id

Abstract. The high groundwater table and the placement of the basement below the groundwater level give rise to several issues, one of which is groundwater seepage. The accumulation of groundwater seepage on the basement floor surface leads to discomfort for the building users, as observed in Building X, located in the Central Semarang Area, Semarang City. A further investigation is required utilizing groundwater seepage modeling on the basement floor to analyze the causes of problems. The methods employed include analytical and numerical approaches facilitated by Geostudio SEEP/W software. The modeling encompasses a basement floor length of 94 meters and ground water level (GWL) elevation ranging from 0 cm to 400 cm relative to the basement floor surface, with 50 cm intervals. The analysis results reveal that higher ground water level elevations concerning the basement surface correspond to more significant seepage discharge values, velocity, and uplift values. Moreover, as the distance from the point on the basement floor increases, seepage discharge values, velocity, and uplift decrease. At the GWL elevation of 300 cm from the basement floor, the observed field seepage discharge value of 44.04 L/day exceeds the modeled seepage discharge value of 43.70 L/day by 0.771%. Meanwhile, the highest modeled seepage discharge value is 44.814 L/day, and the maximum uplift value is 3.034 kN/m², occurring when the GWL elevation matches the ground surface level, likely during the rainy season. The uplift value is deemed safe for the floor plate; thus, addressing the groundwater seepage issue in the basement involves injecting polyurethane material into the basement floor cracks and applying a finishing layer using polyurethane rubber coating.

Keywords: seepage discharge; ground water table; basement; uplift pressure

M. U. H. Al Rasyid and M. R. Mufid (eds.), *Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023)*, Advances in Engineering Research 230,
https://doi.org/10.2991/978-94-6463-364-1_39

1. Introduction

The density of Indonesia's population, especially in big cities, causes limited land for development. As a result, many public places are misused as illegal parking lots due to the narrow parking area, which is different from the capacity of the occupants of the building. One alternative to this problem is the vertical development of buildings, either vertically up or down. In buildings vertically downwards, adding a basement or basement to a vertical building can be used as a parking space to overcome the narrowness of parking space in densely populated urban areas. However, several problems often occur in basement buildings, including groundwater seepage, which causes stagnant water on the basement surface. Seepage can happen because, in general, the elevation of the basement floor is below the groundwater level. Similar to what happened in several buildings in the Central Semarang District area, there were several points of puddles on the parking floor of the basement, including Building X. Building X is the building that has the most significant number of puddles in the area.

This stagnant water causes inconvenience to building users. Therefore, it is necessary to analyze the relationship between the groundwater level and this problem. The SEEP/W subdivision Geostudio software can be used efficiently for seepage modeling. This element-based software can model 2D velocity vector visualization, flow-net line drawings, discharge and seepage velocity calculation, and gradient exit [1]. From the results of modeling and analyses, it is possible to find the cause of water seepage as seen from the groundwater level relationship so that effective and efficient handling can be applied to the problem. Document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables, are not prescribed, although the various table text styles are provided. The formatter must create these components, incorporating the following applicable criteria.

2. literature review

The basic laws of flow through porous media were first stated by Darcy [2], which applied to water flow through saturated soils. However, subsequent research emerged that explained the water flow through unsaturated soil by Richards and Childs & Collins-George. The only difference between these studies is that the hydraulic conductivity of the subsoil is not fixed but varies with varying changes in water content or pore water pressure. Various methods can be used to analyze seepage, which can be classified as analytical and experimental [3].

One example of an analytical method for seepage is using the Geostudio sub-section of SEEP/W software. [1] have analyzed seepage flux by comparing the value of direct observations in the field with modeling in the SEEP/W sub-section Geostudio software and found that the seepage discharges are both significantly the same, so it can be concluded that SEEP/W can be used efficiently for modeling seepage. [3] Groundwater seepage analysis can be carried out efficiently using the Geostudio SEEP/W software, which can estimate parameters such as pore water pressure, seepage discharge, and exit gradient values. Salim et al. [4] showed that seepage under hydraulic structures can be analyzed using the SEEP/W program to estimate minimum and maximum uplift values, exit gradient values , and minimum seepage discharge. Aribudiman [5] has studied that the value of seepage discharge is affected by the elevation of the groundwater table, which is modeled using SEEP/W, and the provision of waterproof materials to the basement floor can be one of the measures that can be taken to deal with seepage. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings and not as an independent document. Please do not revise any of the current designations.

3. Material and methods

3.1 Study Location

Seepage modeling uses a basement floor object that has a length of 94 m and a width of 30 m with a floor elevation of -4 m from the ground surface, as shown in Fig. 1. The basement floor is used on the basement floors of buildings located in the Central Semarang area of Semarang City with a longitudinal cut like in Fig. 1. If there is a foundation in modeling, there is a cut-off process in the water flow from the upstream so that the values of several parameters such as seepage discharge, seepage velocity, and uplift will be smaller. Modeling uses a longitudinal section by taking a critical condition, namely in a place not hit by the foundation, as shown in Fig. 2.

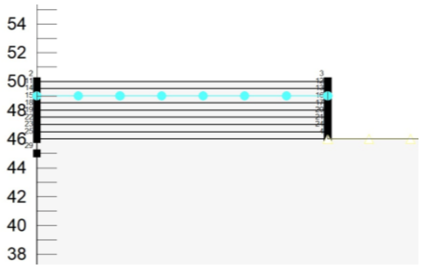

Fig. 1. Elevation of Basement from Ground Surface

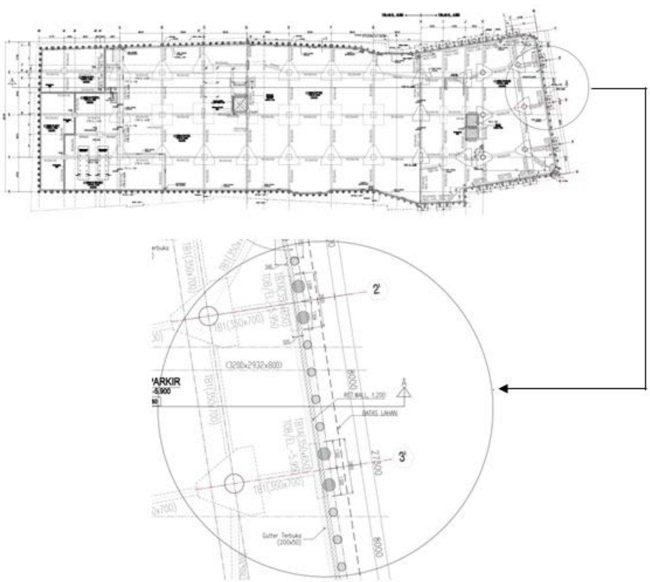

Fig. 2. Basement Floor Plan as a Modeling Reference

Soil data was used using drill logs from the 2013 SPT Test for the area with a groundwater table of -100 cm to the ground surface, as shown in Fig.3.

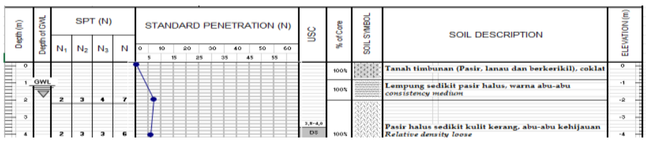

Fig. 3. The Position of Groundwater Level (GWL) in Borehole Data

The modeling was carried out on SEEP/W using a length of 94 m with a groundwater level elevation fluctuating from 0 cm to 400 cm to the ground, as shown in Fig.1.

Field observations were conducted to compare the modeling carried out using the Geostudio software (SEEP/W). The field observations encompassed measuring the area and height of daily water seepage on the basement floor surface of a building in the Central Semarang District. The measurements and calculations of the water accumulation area were executed using a simple method involving approximating a rectangular area by measuring the length and width of the water accumulation. This approach was adopted due to the irregular water accumulation shape and the measuring tools' limitations. These measurements were undertaken to determine the daily groundwater seepage discharge.

3.2 Groundwater Flow

Darcy's law can be employed to define the ability of a fluid to flow through a porous medium under the assumption of soil being homogeneous and isotropic. The seepage velocity can be formulated using Darcy's law, which is given by:

$$Q = kiA \quad (1)$$

$$Hydraulic\ Gradient = i = \frac{\Delta h}{\Delta L} \quad (2)$$

$$\Delta h = h_a - h_b \quad (3)$$

Where Q is the flow rate (flow volume over time), K is hydraulic conductivity, i is the hydraulic gradient, Δh is the head loss, ΔL is the change in length, A is the cross-sectional area, h_a is the total head at point A and h_b is the total head at point B.

3.3 Hydraulic Conductivity

Hydraulic conductivity depends on several factors, including viscosity, grain size distribution, porosity, grain surface roughness, and soil saturation degree. The soil conditions in the field are typically diverse, comprising multiple layers of different soil types. This diversity gives rise to varying values of hydraulic conductivity (k). To simplify calculations, a formulation for the equivalent hydraulic conductivity with a horizontal layer direction exists. Fig. 4, "Vertical Soil Layers," illustrates soil layers and the formulation for horizontal equivalent hydraulic conductivity.

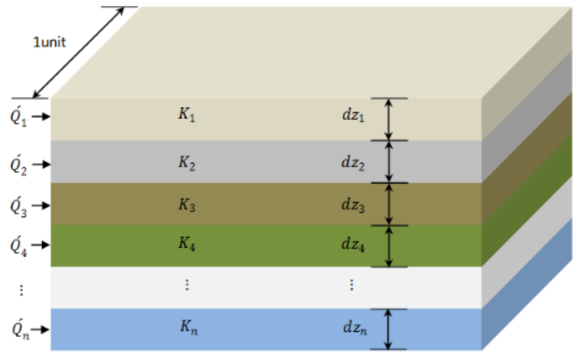

Fig. 4. Vertical Soil Layer

$$k(eq) = \frac{1}{Z}\left(k_2\, d_{z1} + k_2\, d_{z2} + \ldots + k_n d_{zn}\right)$$

3.4 Geostudio SEEP/W

The parameters utilized in the SEEP/W modeling within the Geostudio 2023.1 version 23.1.1.829 software with a student license are as follows:

1. Unit System: A metric system is used for measurements.
2. Scale: A scale of 1:100 is applied.

3. Coordinates: Two-dimensional coordinates are used, with the x-axis representing distance and the y-axis representing elevation.
4. Sketch: A closed polygon sketch resembling a hexagon is created. The model includes a retaining wall and a basement floor. The retaining wall's height matches the elevation of the basement space (4 meters above ground level). The soil next to the retaining wall is approximately 20 meters wide to simulate a more comprehensive water flow, similar to field conditions. The soil elevation is determined based on soil data, as shown in Fig.5.
5. Input Soil Parameters for SEEP/W: Parameters include hydraulic conductivity (k), porosity, specific storage, grain size distribution, and soil type for each layer.
6. Draw Materials in SEEP/W Sketch: Define the soil layers using three different soil types with their corresponding properties.
7. Draw Boundary Conditions and Elevation: Indicate the elevation of the surface water level and potential seepage faces along the lines of the groundwater level and basement floor, as shown in Fig.5.

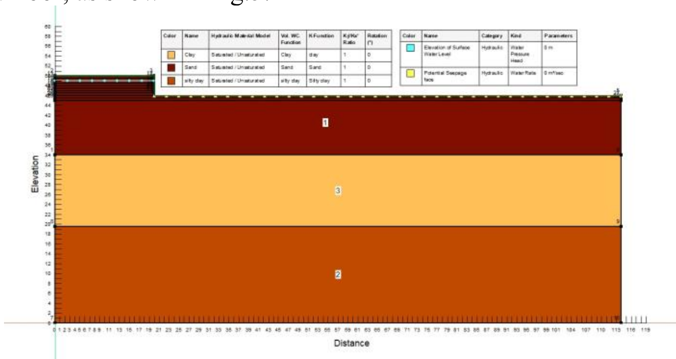

Fig. 5. Basement Floor Modeling

3.5 Problem Management

Iswanto et al. [6] found that the material suitable for crack injection and preventing water leakage in floor slabs is polyurethane. In addition to crack sealing, waterproofing is essential to prevent water seepage. As suggested by Koyaly, Ekka & Sutandi [7], one effective waterproofing method involves using polyurethane rubber-based coatings. This type of waterproofing prevents abrasion caused by friction, making it suitable for basement floors in building structures. Its application is relatively easy, making it an efficient choice for basement floor waterproofing.

4. RESULTS AND DISCUSSIONS

4.1 Calculation of Hydraulic Conductivity Value

The material properties for the soil section of the research object are calibrated in Table 1. The conductivity values for input data in the SEEP/W program are determined by calculating horizontal equivalent hydraulic conductivity with three different layers, as illustrated in Table 2.

Table 1. The range of soil permeability (k) [2]

Soil Type	k (m/s)
Coarse Gravel	$1\text{-}10^{-2}$
Fine Gravel, Coarse Gravel mixed with Medium Sand	$10^{-2}\text{-}10^{-5}$
Fine Sand, Loose Silt	$10^{-5} - 10^{-7}$
Dense Silt, Silty Clay	$10^{-7} - 10^{-8}$
Clay Silt, Clay	$10^{-8}\text{-}10^{-11}$

Table 2. Calibrated Values of Material Properties

No	Depth (m)	Soil Layer/ Type	Soil Conductivity (m/s)
1	0-16	$K_{1\,(eq)}$	9,83 10^{-8}
2	16-31	$K_{2\,(eq)}$	1,78 10^{-8}
3	31-50	$K_{3\,(eq)}$	5,99 10^{-8}

4.2 Flow net Modelling

The SEEP/W software is also utilized to determine flow lines, equipotential lines, velocity vectors indicating seepage flow, and phreatic lines illustrating seepage behavior on the basement floor, as depicted in Fig.6.

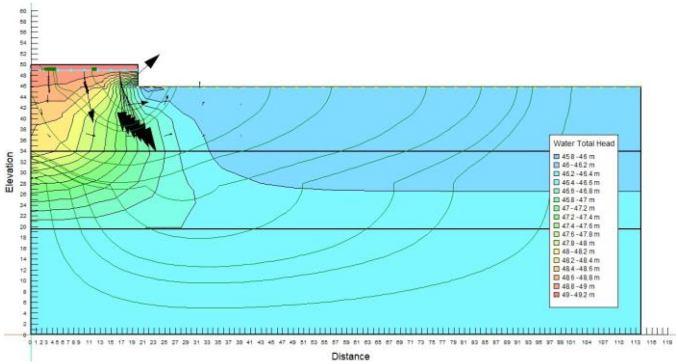

Fig. 6. Flownet Result of SEEP/W Modeling at a Groundwater Level (GWL) Depth of 100 cm from the Ground Surface

In addition to using the SEEP/W software, flow nets can also be visualized using the Damnasht 3.2 software. The flow net results that the Damnasht 3.2 software can depict are illustrated in Fig.7.

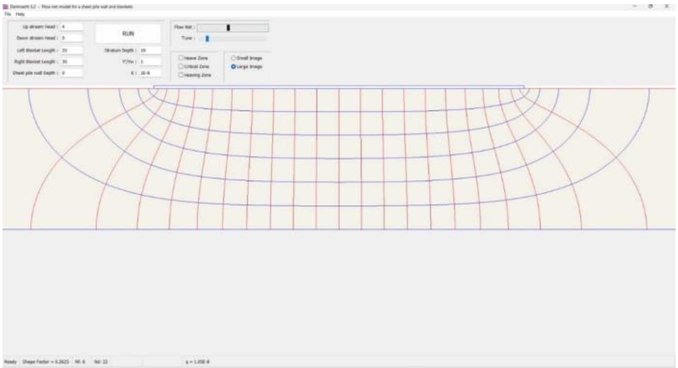

Fig. 7. Flownet Result of Damnasht 3.2 Modeling with a Groundwater Level (GWL) Depth of 100 cm from the Ground Surface

4.3 Analysis of Geostudio Output Data

Table 3 presents the results of the Geostudio SEEP/W software analysis in the form of maximum seepage flux, maximum seepage velocity, and maximum uplift values along the basement floor of the research object, located 20 meters from the point 0 of the x-axis for various fluctuations in the groundwater level. The maximum seepage flux, seepage velocity, and uplift values occur when the GWL depth is 0 cm or equivalent to the ground level: 44.814 L/day, 3.10E-08 m/s, and 3.093 kN/m^2.

Table 3. The result of computation using GeoStudio SEEP/W

Depth Ground Water Level (cm)	Seepage Discharge (L/day)	Seepage Velocity (m/s)	Uplift (kN/m^2)
400	44.814	3.10E-08	3.093
350	41.930	2.88E-08	2.875
300	38.904	2.67E-08	2.664
250	35.722	2.48E-08	2.474
200	32.365	2.34E-08	2.331
150	28.807	2.29E-08	2.281
100	25.004	2.39E-08	2.385
50	20.887	2.71E-08	2.703
0	-4.57E-15	2.05E-21	2.03E-13

The relationship between seepage flux, seepage velocity, and uplift is depicted in Fig.8, Fig.9, and Fig.10, respectively. From these three graphs, it can be observed that the graphs exhibit linear patterns with R-squared values approaching 1. This indicates a strong correlation between the independent and dependent variables, showcasing a consistent change, as seen in linear equations for each graph. As the groundwater level depth increases from the ground surface, the values of seepage flux, seepage velocity, and uplift decrease, and vice versa

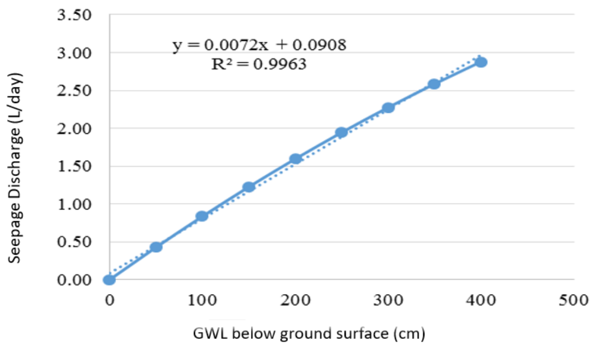

Fig. 8. Graph of Seepage Discharge against Fluctuations in GWL Elevation

From the linear regression analysis of seepage flux against changes in groundwater level (GWL) with a horizontal distance of 27.231 meters from the origin (point 0) along the x-coordinate, a Multiple R-value of 0.9981 is obtained. This indicates an extremely strong correlation between seepage flux and GWL elevation. Meanwhile, the coefficient of determination (R-squared) is 0.9957 or 99.57%, meaning that GWL elevation influences seepage flux by 99.57%, while other factors influence the remaining 0.43%. The significance value is 9.38E-10, less than the alpha value of 0.05. This leads to the conclusion that there is a significant influence between GWL elevation and seepage flux.

Consequently, the seepage flux value decreases as GWL elevation becomes deeper or the distance between GWL and the basement floor decreases. This aligns with the linear function observed in Fig.8, given by the equation $y = 0.0072x + 0.0908$.

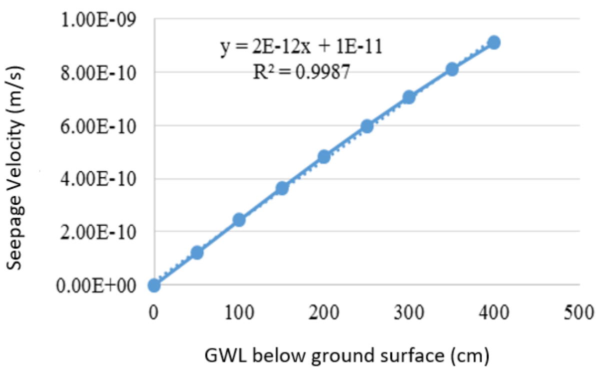

Fig. 9. Graph of Seepage Velocity against Fluctuations in GWL Elevation

From the linear regression analysis of seepage velocity against changes in groundwater level (GWL) with a horizontal distance of 34.462 meters from the origin (point 0) along the x-coordinate, a Multiple R-value of 0.9993 is obtained. This indicates an extremely strong correlation between seepage velocity and GWL elevation. Meanwhile, the coefficient of determination (R-squared) is 0.9985 or 99.85%, meaning that GWL elevation influences seepage velocity by 99.85%, while other factors influence the remaining 0.15%. The significance value is 2.584E-11, less than the alpha value of 0.05. This leads to the conclusion that there is a significant influence between GWL elevation and seepage velocity.

Consequently, the seepage velocity value decreases as GWL elevation becomes deeper or as the distance between GWL and the basement floor decreases. This is in line with the linear function observed in Fig.9, given by the equation y = -2E-12x + 1E-11.

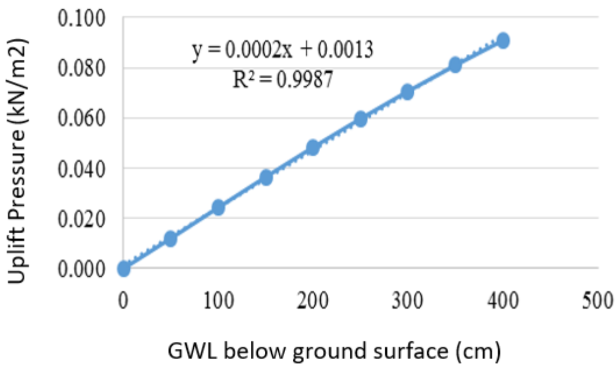

Fig. 10. Graph of Uplift against Fluctuations in GWL Elevation

From the linear regression analysis of uplift against changes in groundwater level (GWL) with a horizontal distance of 34.462 meters from the origin (point 0) along the x-coordinate, a Multiple R-value of 0.9993 is obtained. This indicates an extremely strong correlation between uplift and GWL elevation. Meanwhile, the coefficient of determination (R-squared) is 0.9993 or 99.93%, meaning that GWL elevation influences uplift by 99.93%, while other factors influence the remaining 0.17%. The significance value is 2.585E-11, less than the alpha value of 0.05. This leads to the conclusion that there is a significant influence between GWL elevation and uplift.

Consequently, the uplift value decreases as GWL elevation becomes deeper or the distance between GWL and the basement floor decreases. This is in line with the linear function observed in Figure 10, given by the equation y = 0.0002x + 0.0013.

In the Geostudio software analysis results in Table 3, it can be observed that at a GWL depth of 400 cm from the ground surface, the values of seepage flux, seepage velocity, and uplift experience a drastic reduction. This is because the water pressure on the upstream and downstream sides is equal, causing the water from the upstream not to flow downstream entirely. Part of it flows downward, and some flows toward the basement surface. As a result, the flow net and seepage velocity vectors become irregular, as shown in Figure 11.

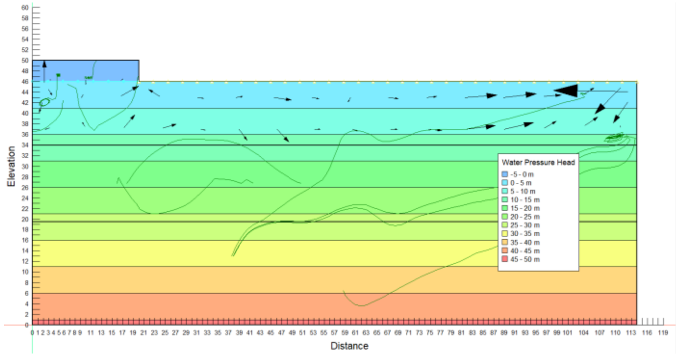

Fig. 11. seepage velocity vectors when GWT depth of 400cm (at the basement floor level)

4.4 Figures and Tables

In the conducted analysis, the uplift value obtained was 3.039 kN/m3. The dead load calculation for the basement floor of the research object, with dimensions as shown in Figure 13, according to the regulation SNI 03-2847-200 [8] regarding dead load calculation, is as follows.

Self-weight = plate thickness x Floor covering load
= 0,3 m x 24 kN/m^3
= 7,2 kN/m^2
Specific weight = Thickness of specimen x Specimen load
= 0,05 x 21 kN/m^3
= 1,05 kN/m^2
Total Load = 8.25 kN/m^2
Uplift value = 4.416 kN/m^2 (Highest total value at GWL elevation of 400 cm)

The calculation results show that the dead load value of the floor > uplift value. Therefore, the floor is secure against uplift. However, the seepage that has occurred requires attention. Cracks on the floor slab need to be filled using polyurethane injection at Rp 250,000.00 per point, followed by finishing with a polyurethane rubber coating priced at Rp 160,000.00 per square meter.

5. Conclusions

From the results of the SEEP/W output analysis, it can be concluded that the values of seepage flux, seepage velocity, and uplift in the basement floor are influenced by the elevation of the groundwater level. As the groundwater level elevation increases relative to the basement floor, seepage flux, seepage velocity, and uplift values also increase, and vice versa.

Based on field observations, when the groundwater level (GWL) was at an elevation of -100 cm from the ground surface, the observed seepage flux was 44.04 L/day, whereas, in the SEEP/W modeling, the calculated total seepage flux at that GWL elevation was 43.70 L/day. It can be inferred that the field observation recorded a seepage flux value higher than the SEEP/W modeling result by approximately 0.771%. There was a difference between the field measurement results and the modeling results, where the modeling results had a seepage discharge that was smaller than the field measurements. This is possible because in the modeling method, simplification conducted the input soil layers to only 3 layers of soil which is the permeability calculated as equivalent permeability coefficients. The highest seepage flux value recorded was 44.814 L/day, and the maximum uplift value was 3.034 kN/m^2, both occurring when the GWL elevation was equivalent to the ground surface, which is likely during the rainy season.

Given that the dead load of the floor > uplift value, the basement floor is secure against uplift. The adopted solution involves using polyurethane injection material to fill existing cracks and finishing with a polyurethane rubber coating. The overall cost for this repair approach amounts to Rp 20,820,000.00.

REFERENCES

1 K. Anjali and P. Hangargekar.: "Seepage Analysis of Ujjani Dam using Geo-Studio Software," *IJSRD-International J. Sci. Res. Dev.*, vol. 4, no. 11, pp. 2321–0613, [Online]. Available: www.ijsrd.com (2017)

2 D. Braja M, *Advanced Soil Mechanics*.: New York: McGraw-Hill, (1995).

3 N. M. Nedawi and M. T. Al-Hadidi.: "Seepage and Slope Stability Analysis for Hemrin Earth Dam in Iraq Using Geo-Studio Software," *Solid State Technol.*, vol. 63, no. 3, pp. 3434–3448, [Online]. Available: http://www.solidstatetechnology.us/index.php/JSST/article/view/4479 (2020)

4 B. S. Salim, Ibtihal H; Othman.: "The Effect of inclined intermediate Sheet Pile on Seepage Properties Under Hydraulic Structure Using SEEP / W Program The Effect of inclined intermediate Sheet Pile on Seepage Properties Under Hydraulic Structure Using SEEP / W Program," *2nd Int. Sci. Conf. Eng. Sci. (ISCES 2020)*, no. 1076 (2021) 012131, doi: 10.1088/1757-899X/1076/1/012131. (2021)

5 I. N. Aribudiman and Y. E. Kurniawan Nggae.: "Penggunaan Progra[1] I. N. Aribudiman and Y. E. Kurniawan Nggae, 'Penggunaan Program Geo-Studio Seep/W Untuk Menentukan Rembesan Air Lindi Pada Tanah Lempung,' J. Spektran, vol. 10, no. 2, p. 133, 2022, doi: 10.24843/spektran.2022.v10.i02.p10.m Geo-Studio," *J. Spektran*, vol. 10, no. 2, p. 133, doi: 10.24843/spektran.2022.v10.i02.p10. (2022)

6 Iswanto, L. Agustina, T. Hamzah, and A. Siswanto.: "Desain Operasional Prosedur Pemeliharaan dan Perawatan pada Gedung Summarecon Digital Center (SDC) Ditinjau Dari Keandalan Bangunan," *Potensi J. Sipil Politek.*, vol. 21, no. 1, p. 27, 2019, doi: 10.35313/potensi.v21i1.1313.

7 A. Koyaly, Ekka; Sutandi.: "Studi Perbandingan Pemasangan Material Waterproofing Jenis," vol. 1, no. 1, pp. 131–138, (2018)

8 Badan Standardisasi Nasional.: "Persyaratan Beton Struktural untuk Bangunan Gedung," *Sni 2847-2019* no. 8, p. 720, (2019)