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Application of ChatGPT in seepage-induced slope stability

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ABSTRACT

ChatGPT has been recently applied to many engineering fields including geotechnical engineering. This study investigates the chance of using ChatGPT for seepage-induced slope stability problems based on the grid and radius method. The Python code for solving seepage and slope analysis was first generated, followed by the coupling of those two analyses was performed using ChatGPT. In addition, the grid search method and three scenarios of optimization methods were applied to determine the best optimization method for the computational efficiency of the developed framework. The comparable factor of safety (maximum error of 1.86%) shown in this study compared to those obtained by commercial software demonstrated the feasibility of using ChatGPT-generated code for seepage-induced slope stability analysis. Furthermore, the use of optimization techniques enabled up to a 70% reduction in calculation time, and the relatively easy implementation of optimization methods using ChatGPT implies that the appropriate prompts in ChatGPT can provide a wide range of applications in slope stability analysis.

1. Introduction

Seepage-induced slope stability has been investigated using analytical (Iverson, 2000), numerical (Lu and Godt, 2008), and experimental techniques (Wu et al., 2015) due to its importance in assessing the stability of slope under extreme weather. Key parameters of seepage-induced slope stability include slope geometry (e.g. height and slope angle), soil properties (e.g. unit weight, cohesion, and friction angle) (Cha and Kim, 2011; Harabinová and Panulinová, 2020; Habtemariam et al., 2022), and changes in pore water pressure in the soil (Bathe and Khoshgoftaar, 1979; Nath, 1981; Arshad and Muneer Babar, 2014). Because of the complexity of coupled analyses, commercial software with underlying numerical schemes is typically required to assess large-scale seepage-induced slope stability (Li and Desai, 1983; M Abbas and Zainab Ali Mutiny, 2018; Malik and Karim, 2020; Siacara et al., 2020; Paul et al., 2024). Therefore, the AI-aided (e.g., interpretable machine learning algorithms) predictions for slope stability analysis have been investigated in recent studies (Abdollahi et al., 2024; Suman et al., 2016; Luo et al., 2021; Lin et al., 2018; Wu et al., 2025).

ChatGPT, created by OpenAI, has undergone significant evolution since the introduction of GPT-1 in June 2018 (Wu et al., 2023). It is the most advanced Large Language Model (LLM), designed to generate and understand natural language through pre-training based on the transformer architecture (Liu et al., 2023). The key features of ChatGPT include conversational responses, extensive usability, contextual understanding, and language processing capabilities (Ray, 2023). Due to these powerful features, ChatGPT has been applied to many fields including geotechnical engineering such as slope stability under dry conditions, data mining from cone penetration test results, and educational aspects of geotechnical engineering (e.g., earthquake education) (Sohail et al., 2023; Aluga, 2023; Kim et al., 2024; Rane et al., 2024; Botana and Recio, 2024; Ray, 2024). These studies showed the chance of applying ChatGPT in geotechnical engineering.

Although the majority of slope failures are induced by seepage (Hu et al., 2025; Jadid et al., 2020; Rajabian, 2023), no study has investigated seepage-induced slope stability using ChatGPT to date. Therefore, this study investigates the application of ChatGPT on seepage-induced slope stability based on Bishop's simplified method (Bishop, 1955; Fredlund and Krahn, 1977; Zhu, 2008). The Python code for seepage analysis was generated using ChatGPT, followed by generating the code for seepage-induced slope stability analysis. The results of the seepage-induced analysis were compared with those of commercial software to show the validity of using ChatGPT under many scenarios. In addition, the best optimization method of the developed framework for

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computational efficiency and error was evaluated and discussed.

2. Methodology

2.1. Model construction

In this study, the Python code for slope stability analysis was generated using ChatGPT-o1. Two types of slopes were selected for seepage-induced slope stability: the typical configuration of a two-dimensional slope problem (Type 1) and the slope stability problem of an earth dam (Type 2). Type 1 is a slope with predefined coordinates of groundwater level (Fig. 1(a)), whereas the phreatic surface was determined by seepage analysis in Type 2 slope for the earth dam (Fig. 1(b)). The factor of safety (FoS) for dry slope stability of Types 1 and 2 (Fig. 1) was first evaluated, followed by the validation of FoS using SLOPE/W. Then, the level of water was introduced using ChatGPT to perform seepage-induced slope stability. The FoS at some scenarios of water levels for Types 1 and 2 slopes were evaluated from the developed framework used in ChatGPT to validate the FoS values evaluated from ChatGPT with those evaluated from SEEP/W coupled with SLOPE/W. Note that the soil beneath the dam was not modelled separately in this study to simplify comparison with SLOPE/W results. This assumption ensured consistent boundary conditions and reduced model complexity. Future studies will consider more realistic conditions by incorporating layered ground profiles and foundation effects. Further explanation of slope stability and seepage analysis are documented in the following sections.

2.2. Slope stability analysis

The Bishop's simplified method was selected for slope stability of soil in SLOPE/W and ChatGPT slope analysis. Therefore, unit weight (γ_t), effective cohesion (c'), and effective internal friction angle (ϕ') were selected as key properties of soils. The properties of the soil used in all types of slope adopted in this study are summarized in Table 1. The FoS using Bishop's simplified equation can be calculated (Bishop, 1955):

$$FoS = \frac{1}{\sum W_n \sin\alpha_n} \sum \left[c'b + (W_n - r_w h_n b)\tan\phi'\right] \left[\frac{\sec\alpha_n}{1 + \frac{\tan\alpha_n \tan\phi'}{FoS}}\right] \quad (1)$$

$$Error\ (\%) = \left|\frac{FoS_{ChatGPT} - FoS_{SLOPE/W}}{FoS_{SLOPE/W}}\right| \times 100 \quad (2)$$

where W_n is the weight of nth slice (kN), α_n is the angle of the bottom center point of the slice, c' is the cohesion (kPa), b is the width of the slice (m), h_n is the height distance between the bottom center of the slice and the water level (m), γ_w is the unit weight of water (kN/m^3), and ϕ' is the internal friction angle (degree). All variables are illustrated in Fig. 2. The error between ChatGPT and SLOPE/W was calculated using Eq. (2).

In this study, the grid and radius method (Fredlund, 1981; Fredlund, 1984; Azizi et al., 2019) was adopted to evaluate the failure surface with the lowest FoS. The center coordinates of the failure surface were assumed as grid point within the predetermined rectangular area where the radius between the center and the failure surface can be used to calculate the FoS. Because the lowest-FoS failure surface can be determined by calculating FoS of many grid points within the rectangular area, the optimization technique can be applied to evaluate the lowest-FoS failure surface with high computational efficiency. Therefore, this study selected four techniques (grid search, hill climbing, adaptive mesh refinement (AMR), hill climbing combined with AMR) (Berger and Oliger, 1984; Sathiyaraj et al., 2022) to evaluate the best optimization technique for finding the lowest-FoS failure surface using ChatGPT. Grid search is a method of calculating FoS in all grid points within a domain. The hill climbing method is a local search algorithm that allows moving the center of slope to the direction of lowest neighboring FoS. AMR explores the global coarse movement of center of slope throughout the domain, followed by the fine movement to find the center of the lowest-FoS failure surface. To compensate the significant initial guess-dependent computational time for hill climbing method, hill climbing method combined with AMR was also adopted in this study.

Table 1
Properties of soil used in this study.

	Type 1	Type 2(a)	Type 2(b)	Type 2(c)	Type 2(d)
c' (kPa)	10	5	22	29	8
ϕ' (°)	20	27	32	18	20
γ_t (kN/m^3)	15	20	13	16	18

The geometry of slope was first defined by inserting the coordinates of domain (Fig. 3). Then the key soil properties such as c', ϕ', and γ_t were defined, followed by generating the rectangular area with the size of grid and the range of radius for grid and radius method. The number of slices was fixed as 30 in this study, as shown in the literature (Kang et al., 2016), in which the converged FoS was obtained at the number of slices > 30. Because ChatGPT implicitly implemented Bishop's slice method through prompt-based instructions, the mathematical expression shown in Eq. (1) was not directly applied to ChatGPT. Only the simple definitions of pore water pressure ($\gamma_w h_n$ in Eq. (1)) and the weight of slice (W_n in Eq. (1)) were required.

It can be noted that the error of FoS between ChatGPT and SLOPE/W for dry slope (Type 1) was first evaluated as 1.37% (FoS for ChatGPT and SLOPE/W were 1.172 and 1.156), which can be attributed to the fact that the toe of each slice was adopted in the calculation (Fig. 4). Therefore, the prompt for modifying this into the bottom center of each slice was required, where the error of 0.17% (FoS for ChatGPT becomes 1.154) was evaluated after the modification. It can be inferred that the utilization of ChatGPT does not always provide the perfect implementation of given method in which the prompt-based manual modification would be required as shown in abovementioned implementation of Bishop's method. The water level in the domain was added for seepage-induced analysis where initial water pressure throughout the domain was automatically calculated. In Type 1, the water level coordinates were provided for the phreatic line whereas slope and coordinates every 0.1 m were applied to describe curved phreatic line in Type 2 slope.

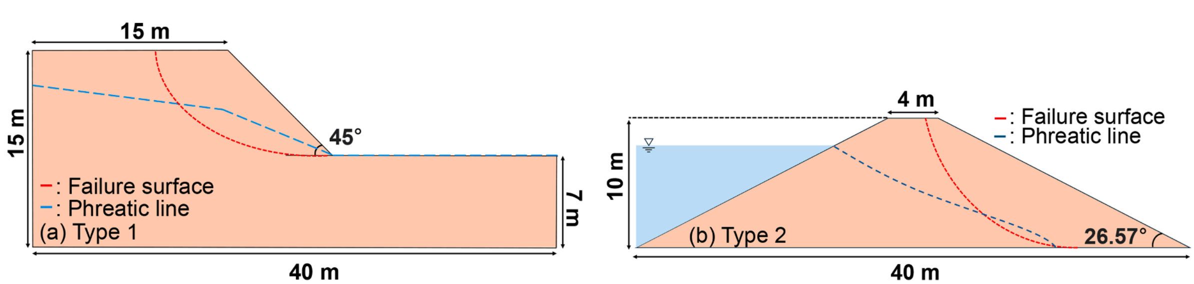

Fig. 1. Two types of slopes for seepage-induced slope stability selected in this study: Type 1 slope ((a)) and Type 2 slope ((b)).

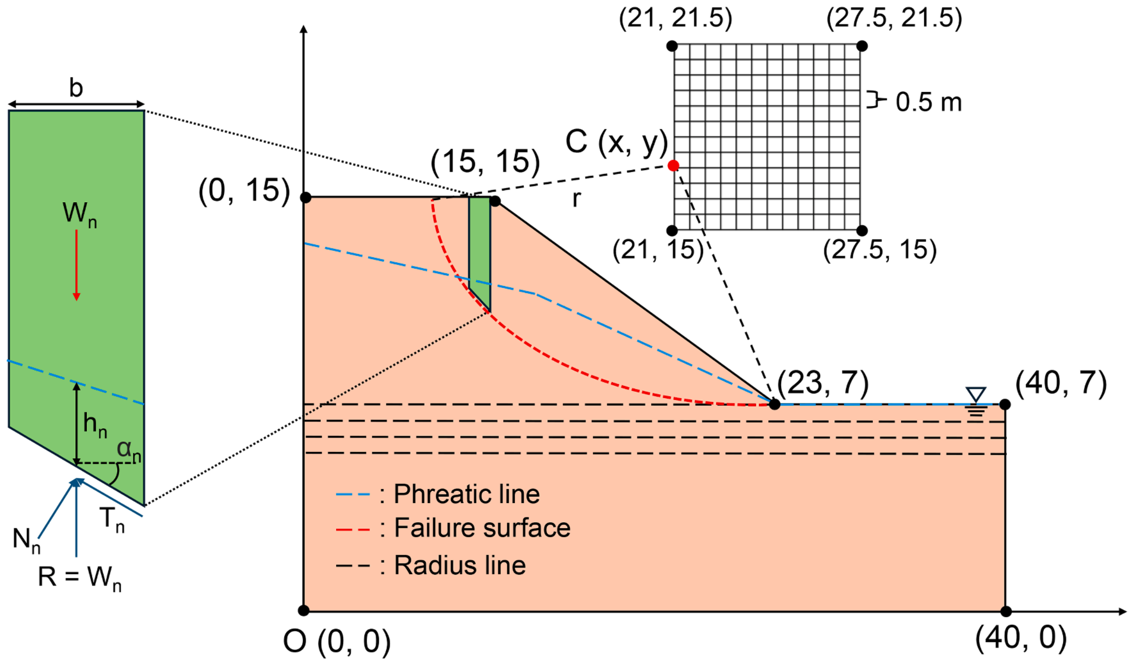

Fig. 2. A schematic illustration of the grid and radius method with Bishop's simplified method adopted in this study.

User : I need a Python script that does the following:

- Slope coordinates: [(0, 0), (0, 15), (15, 15), (23, 7), (40, 7), (40, 0), (0, 0)].
- Soil properties: c'=10, ϕ'=20, γ_t=15
- Number of slices: 30
- Slip-Circle Grid Search Ranges: x_center in (21.0, 27.5) with step 0.5
  y_center in (15.0, 21.5) with step 0.5
  r_target in {7, 6, 5, 4, 3}, and radius = y_center - r_target
- Calculation Steps

For each candidate circle center (x_center, y_center) and each r_target, compute the radius as radius = y_center - r_target. Proceed only if radius > 0. Construct the circle using the computed radius. Intersect the circle with the slope polygon. Slice the intersection area vertically. Perform a Bishop's simplified factor of safety calculation. Identify the slip surface with the lowest factor of safety.

Fig. 3. Prompts for basic structure of slope stability analysis.

2.3. Seepage analysis

Fig. 5 presents a schematic of the Type 2 slope for seepage-induced slope stability analysis. The total hydraulic head throughout the domain was computed using the Laplace equation, which was solved by using the Gauss-Seidel method (Yoon and Jameson, 1988; López-Acosta and González-Acosta, 2015; Vázquez-Báez et al., 2019). The hydraulic head throughout the domain was iteratively calculated until the convergence criterion $< 10^{-4}$ m was achieved, where ChatGPT was employed to calculate pore water pressure and phreatic line. The size of the grid = 0.4 m in x and y directions was generated in ChatGPT (Fig. 5). The key prompts of seepage analysis and validation of seepage analysis with SEEP/W are illustrated in Fig. 6(a) and (b). Fig. 6(c) presents a comparison of pore water pressure values between SEEP/W and ChatGPT at the same coordinate points.

2.4. Seepage-induced slope stability analysis

To perform seepage-induced slope stability analysis, the phreatic line obtained from seepage analysis was extracted using ChatGPT. The numerically identified phreatic line at the interval of 0.1 m using the uniform line segmentation method was applied to slope stability analysis in which the obtained FoS was validated with FoS obtained from

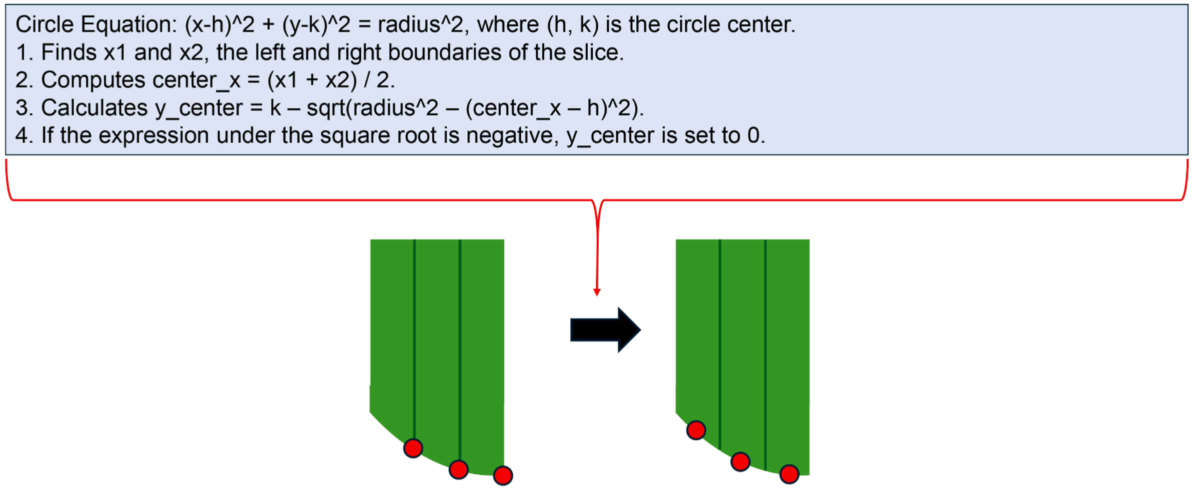

Fig. 4. The prompt for modifying the toe of each slice to the bottom center of each slice.

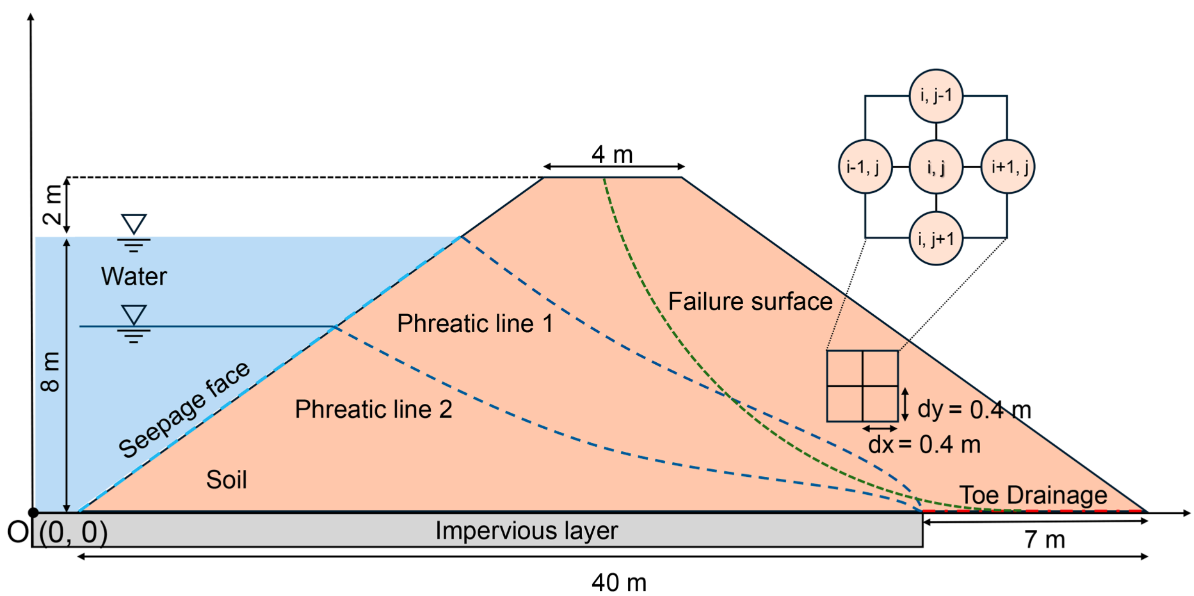

Fig. 5. Schematic of Type 2 slope for seepage-induced slope stability analysis.

SEEP/W coupled with SLOPE/W. For Type 2 slope, FoS values corresponding to the water level at the upstream = 0, 2, 4, 6, and 8 m were evaluated and validated to show the ChatGPT framework developed in this study can apply to a wide range of head differences. Prompts related to seepage-induced slope stability and the adjustment of upstream water level are illustrated in Fig. 7.

3. Results and discussion

3.1. Type 1 slope

Fig. 8(b) shows the visualization of seepage-induced slope stability analysis for Type 1 using ChatGPT (The part of Python script is shown in Fig. S1). As seen in Fig. 8, FoS = 1.031 and 1.033 were evaluated using ChatGPT and SLOPE/W (error = 0.19%), which indicates that the ChatGPT framework well-simulated the Type 1 slope.

Fig. 9 illustrates the required computational time as a function of the initial guess for the hill climbing method. The initial guess of (21, 15), (21, 21), (27, 21), and (27, 15) corresponded to the calculation time of 3.40 (Fig. 9(a)), 4.11 (Fig. 9(b)), 7.35 (Fig. 9(c)), and 22.37 (Fig. 9(d)) sec respectively, which indicate that the initial guess of hill climbing method substantially affects the computational efficiency of the developed framework. Notably, it was found that the initial guess of (27, 15) resulted in a higher calculation time (22.37 sec) than the grid search method (13.75 sec) without applying any optimization method. This implies that the application of the hill climbing method may not be an effective method for the computational efficiency higher than the grid search method.

Fig. 10(a) and (b) show the visualization of AMR and hill climbing combined with AMR methods. As seen in Fig. 10(a), the coarse search of the center point with an interval of 1 m was first performed, followed by a fine refined search to evaluate the accurate center point for the lowest FoS slope. In addition, a relatively low number of visited points was obtained for the AMR method as shown in Fig. 10(a). Fig. 10(b) shows a coarse search at 1 m intervals and then setting the lowest FoS in the search as the initial guess for hill climbing. By defining only the grid domain, it is possible to automatically select an initial guess for the hill climbing method near the location exhibiting the lowest FoS. Consequently, explicit specification of the initial guess for hill climbing is unnecessary, minimizing variability in results.

Fig. 11 illustrates the calculation time (Fig. 11(a)) and the number of estimates (Fig. 11(b)) for four techniques. As seen in Fig. 11, applying

(a) Please provide a Python script that performs a 2D seepage analysis using the Gauss-Seidel method on a domain with vertices at (3,0), (23,10), (27,10), and (47,0). The boundary condition is p=8 on the line from (3,0) to (19,8) and p=0 on the line from (40,0) to (47,0). Use a grid spacing of Δx=Δy=0.4. The script should:

1. Construct the grid
2. Mark boundary conditions
3. Solve the Laplace equation with Gauss-Seidel
4. Plot the hydraulic head distribution and equipotential lines
5. Show the execution time and the number of iterations required for convergence

Provide the complete Python code including imports and a main function

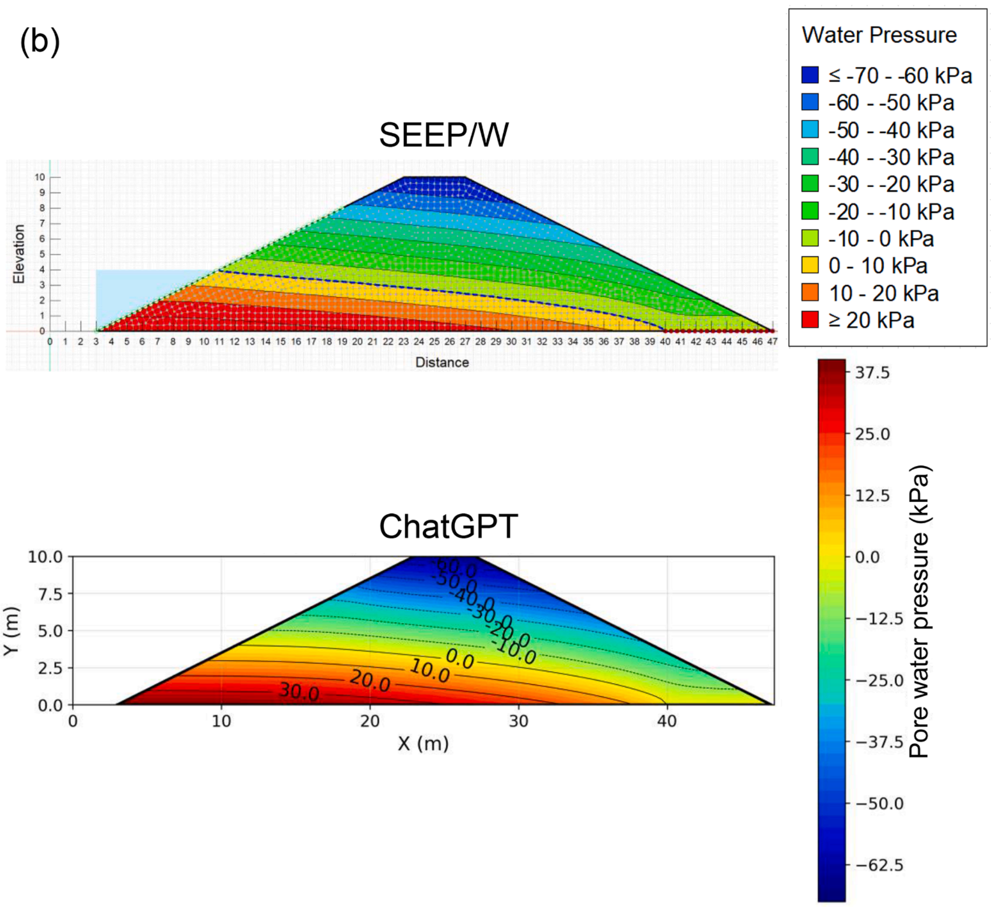

Fig. 6. Prompts for seepage analysis in ChatGPT ((a)), comparison of seepage analysis between SEEP/W and ChatGPT ((b)), and pore water pressure throughout the domain using SEEP/W and ChatGPT ((c)).

the optimization algorithms is beneficial in calculation time and number of estimates compared to the grid search method. In addition, the high variation of calculation time and corresponding number of estimates for the hill climbing method implies that AMR or hill climbing combined with AMR are better optimization technique than the hill climbing method for using the developed framework. Although the AMR method shows the lowest calculation time with the number of estimates among the four methods, the hill climbing combined with AMR showed higher accuracy (error = 0 %) than AMR only (error = 0.0058 %) in this study. Therefore, it can be recommended that combining hill climbing with

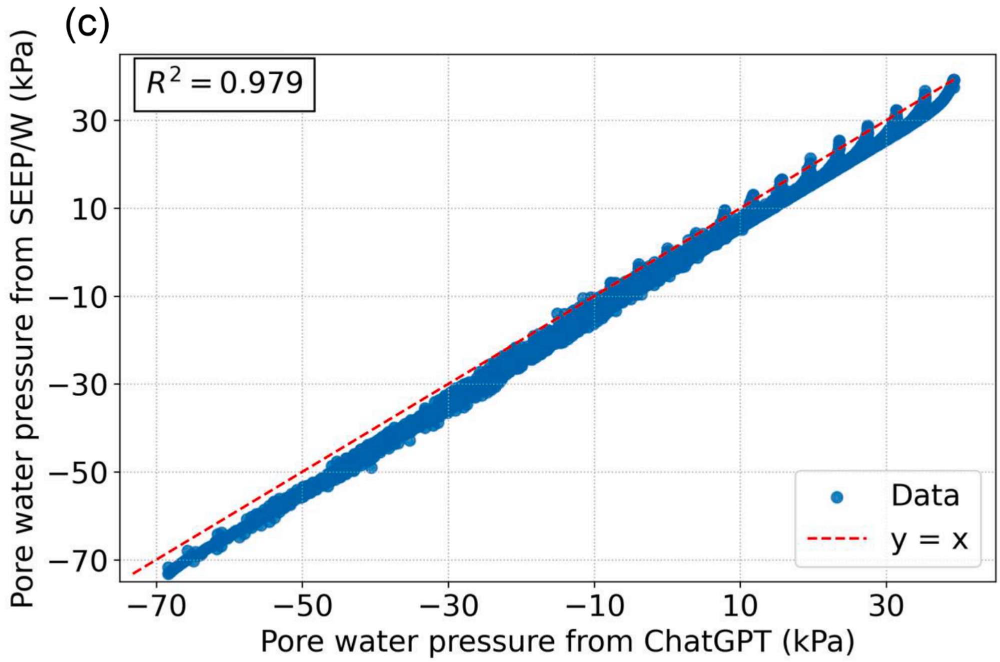

Fig. 6. (*continued*).

Generate code to analyze seepage at upstream water levels 0, 2, 4, 6, and 8 m.
Then extract the phreatic lines for each water level and add them to the slop stability analysis.

- Soil properties: c'=5, ϕ'=27, γ=20
- Number of slices: 30
- Slip-Circle Grid Search Ranges: x_center in (42.0, 53.5) with step 0.5
  y_center in (20.0, 31.5) with step 0.5
  r_target in {5, 4, 3, 2, 1, 0}, and radius = y_center - r_target

Fig. 7. Prompt for seepage-induced slope stability analysis and the adjustment of upstream water level.

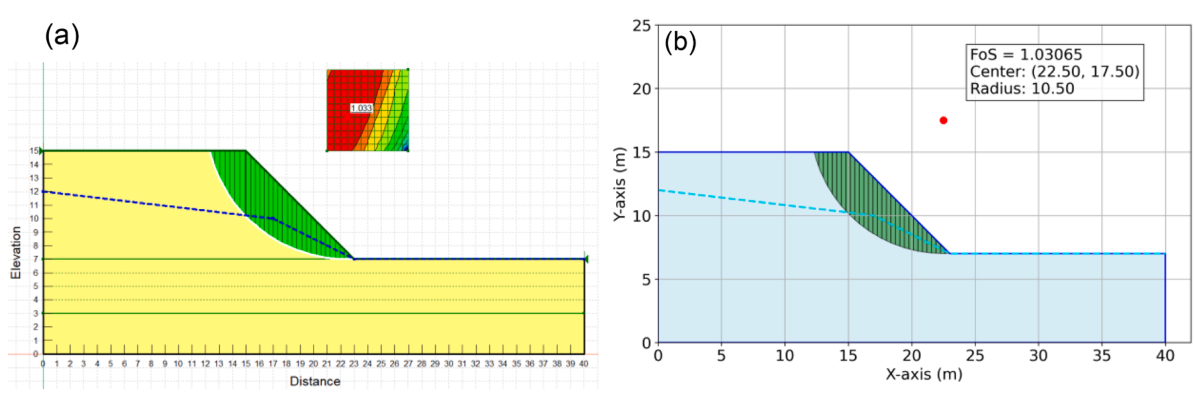

Fig. 8. Illustration of Type 1 slope using SLOPE/W ((a)) and ChatGPT ((b)).

AMR may provide the best optimization for Type 1 slope.

The results shown in Fig. 11 imply that the advantages of using ChatGPT include the application of any optimization technique to the developed framework. Besides optimization methods, the user-defined alternation of the framework is easily achieved because the developed framework was written in Python. Therefore, if the appropriate prompts for the accurate model are secured, the alternation of optimization methods can be easily achieved by ChatGPT without coding any mathematical details as most typical optimization methods are embedded in ChatGPT.

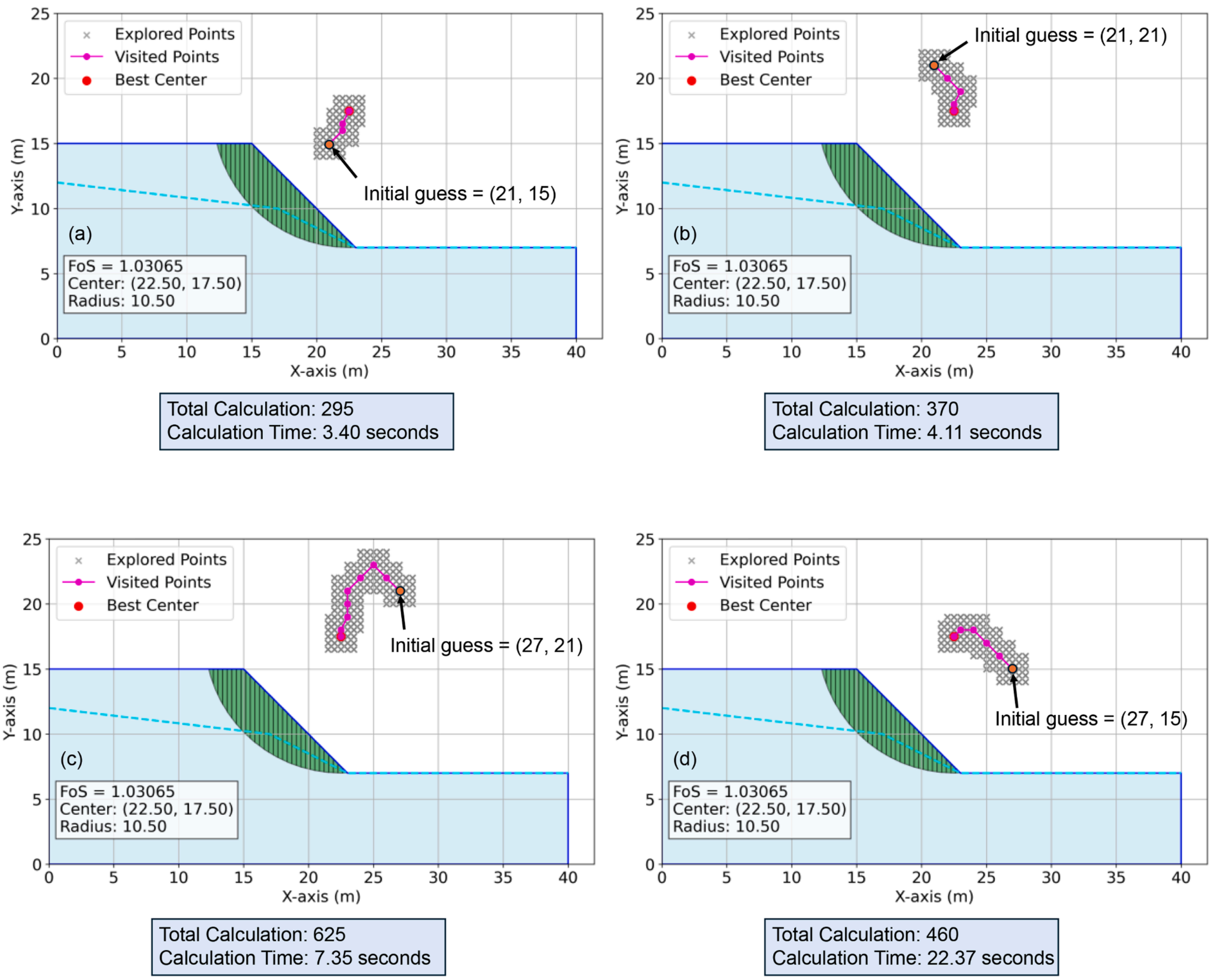

Fig. 9. Hill climbing method at the initial guess = (21, 15) ((a)), (21, 21) ((b)), (27, 21) ((c)), and (27, 15) ((d)). Five calculations were performed at each visited point.

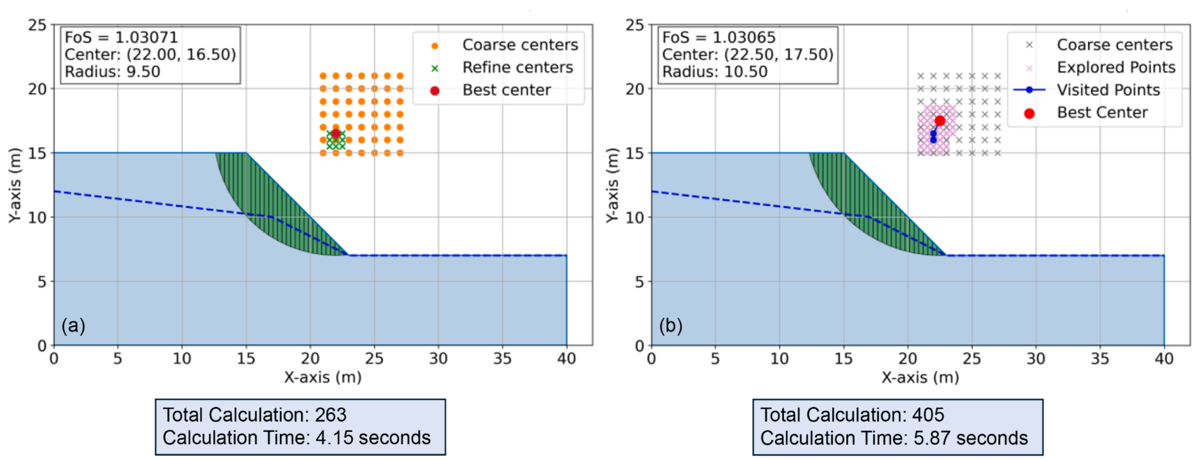

Fig. 10. Example visualization of AMR method ((a)) and AMR combined with hill climbing method ((b)).

3.2. Type 2 slope

Fig. 12 illustrates the equipotential line (Fig. 12(a)) and pore water pressure (Fig. 12(b)) when the water level = 8 m (The part of Python script is shown in Fig. S2). As seen in Fig. 12, the visualization and the calculation of equipotential line and pore water pressure can be achieved using ChatGPT. The results shown in Fig. 12 are consistent with those obtained from SEEP/W. Note that the simple single-line prompt can calculate and visualize pore water pressure throughout the domain (Fig. 12(b)).

As seen in Fig. 13, the phreatic lines with appropriate pore water pressure were successfully imported to the slope stability domain using ChatGPT (The part of Python script is shown in Fig. S3). In addition, the FoS between ChatGPT and SLOPE/W at soil properties ranging from $\gamma_t =$

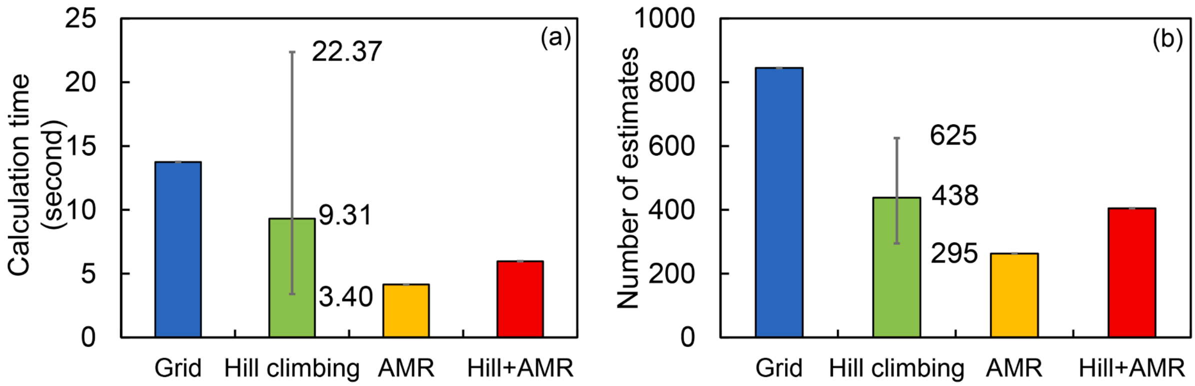

Fig. 11. Calculation time ((a)) and number of estimates ((b)) for grid search, hill climbing, AMR, and AMR combined with hill climbing (Type 1 slope).

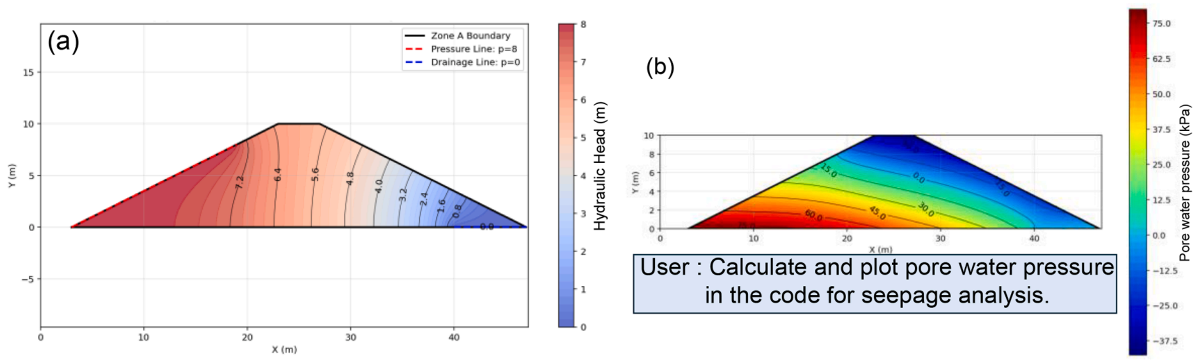

Fig. 12. Equipotential lines ((a)) and pore water pressure ((b)) generated by ChatGPT for Type 2 slope.

13 – 20 kN/m^3, $c' = 5 – 29$ kPa, and $\phi' = 18 - 32°$ are illustrated in Fig. 14 (ranges of soil properties were selected from previous studies (Phoon and Kulhawy, 1999; Mollahasani et al., 2011)). As anticipated, FoS decreases as the water level increases because of seepage flow through the earth's structure. In addition, the developed framework using ChatGPT shows FoS values consistent with SLOPE/W with low error except for water level = 8 m (Fig. 14). Table 2 presents the errors resulting from changes in upstream water levels and soil properties. This relatively high error can be attributed to the seepage analysis based on the finite difference method (FDM) for ChatGPT whereas finite element method (FEM)-based seepage analysis was performed for SEEP/W. The FDM scheme selected in ChatGPT for seepage analysis in this study may have limitations in capturing sharp changes in hydraulic gradient and boundary conditions at complex geometry. In contrast, the FEM scheme used in SEEP/W can apply boundary conditions at complex geometry under high hydraulic gradient variations (López-Acosta and González-Acosta, 2015). Therefore, errors of FoS values between Geostudio and ChatGPT shown in this study may be attributed to the abovementioned difference between FDM and FEM schemes for seepage analysis. Further investigation would be required to develop FEM-based seepage-induced slope stability using ChatGPT, as shown in the previous study for consolidation (Kim et al., 2025). The framework of FEM-based seepage analysis using ChatGPT may be required in future work. Nevertheless, the results shown in Fig. 14 indicate that the developed framework well simulates the seepage-induced slope stability for a wide range of soil properties.

Fig. 15 shows the calculation time and number of estimates for grid search and three optimization methods. As seen in Fig. 15, the water level does not substantially affect the calculation time (Fig. 15(a)) and number of estimates (Fig. 15(b)) for grid search and three optimization techniques. The best-performing optimization technique is dependent on the geometry of the slope as seen in Figs. 11 and 15, where the lowest calculation time was obtained using AMR and hill climbing for Type 1 and Type 2 slopes, respectively. Note that the range of calculation time and number of estimates shown in Fig. 15 for the hill climbing technique can be attributed to the four initial estimates at the corners of the predetermined square area (Fig. 2).

3.3. Discussion

As seen in Fig. 7, the results shown in this study imply that the application of ChatGPT can effectively calculate the method of slices-based slope stability without mentioning the area and angle of each slice or providing a detailed definition of iterative calculation. For example, ChatGPT used its own algorithm for calculating the area of curvilinear polygons, in which the prompt related to the calculation of area for the method of slice is not required. Note that the calculation of complex areas using the simple prompt for ChatGPT can also be found in the literature (Botana et al., 2024; Yunianto et al., 2024). In addition, applications of ChatGPT enable capturing the calculation error relatively easily through the quick documentation of required information (DePalma et al., 2024). For example, the angle of each slice in this study was initially evaluated at the toe of the slice, which led to a significant error in FoS. The quick documentation for the angle of slice (Fig. 16) from a simple prompt allowed fixing the angle of slice into the angle at the bottom center of slice (Fig. 4). ChatGPT also allowed users to easily add water level using single prompt, which mentioned coordinates of water level and calculation of pore water pressure. Overall, even though ChatGPT does not provide a user-friendly graphical interface, the utilization of ChatGPT can effectively substitute commercial software for relatively simple slope stability problems. With the basic knowledge of slope stability, using ChatGPT allows seepage-induced slope stability analysis without the effort for detailed coding. As shown in Figs. 11 and 15, the selection of the best optimization methods can be easily achieved

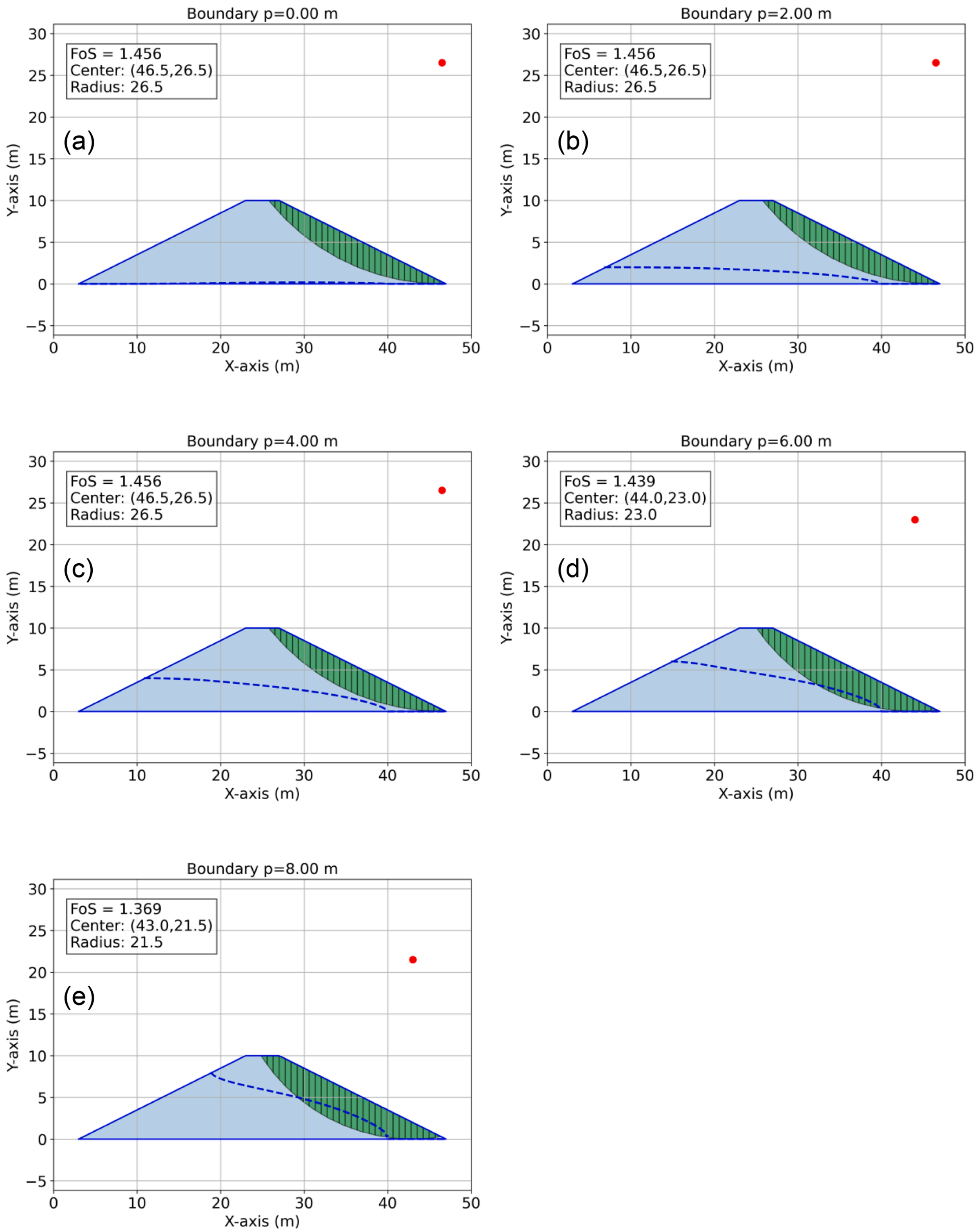

Fig. 13. Seepage-induced slope stability analysis results at upstream water level = 0 ((a)), 2 ((b)), 4 ((c)), 6 ((d)), and 8 m ((e)) ($\gamma_t = 20$ kN/m^3, $c' = 5$ kPa, and $\phi' = 27°$).

by ChatGPT. Although hill climbing and AMR methods to find the optimal center of slope were only investigated in this study, the another aspects of slope stability analysis (e.g., grid resolution) may be also optimized using ChatGPT. In addition, hill climbing combined with AMR methods indicates that the combination of optimization algorithms can be also achieved using ChatGPT. It can be noted that the combination of two individual algorithms using ChatGPT (data retrieval code and HTML rendering code) can be also presented in literature for web development (Biswas, 2023).

Another advantage of using ChatGPT is the ability to reach appropriate methodology from simple prompts. For example, the methodology of the Gauss-Seidel method to solve the Laplace equation for seepage

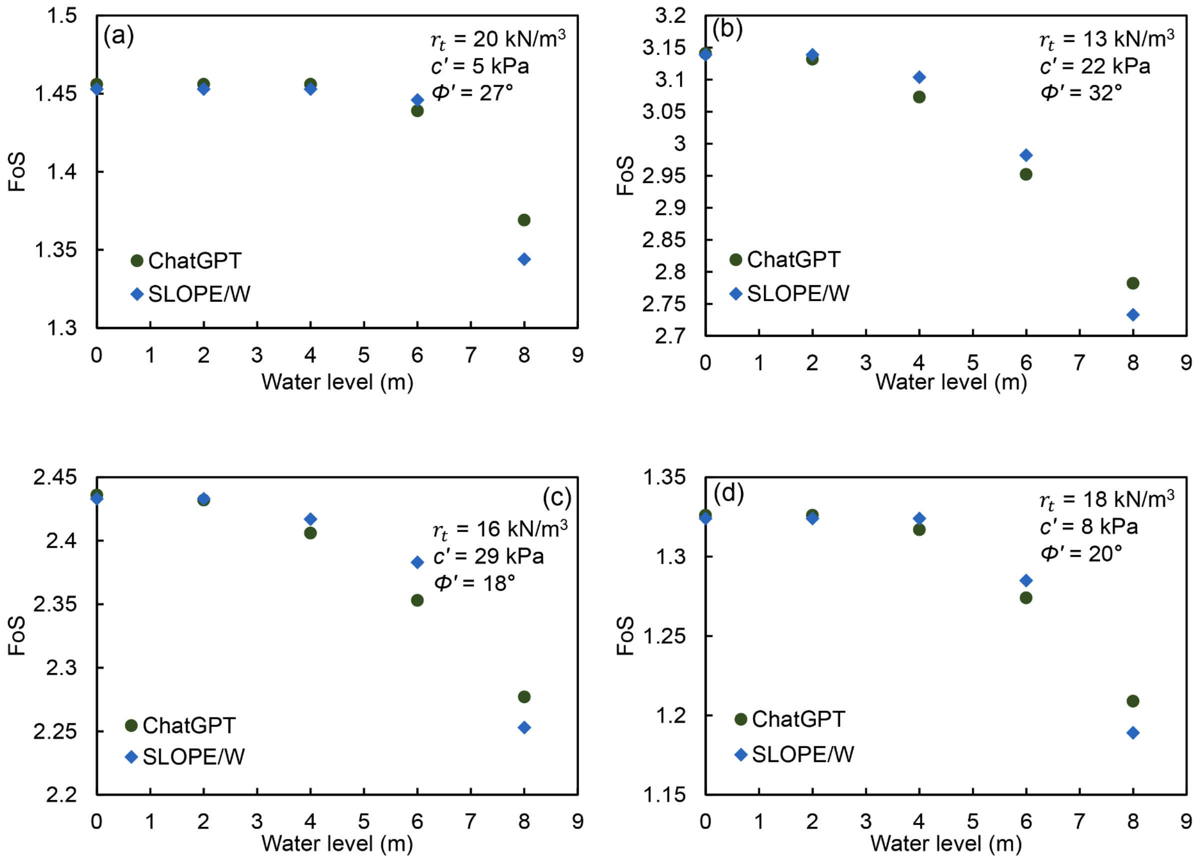

Fig. 14. FoS as a function of upstream water level for a range of soil properties ((a): $\gamma_t = 20$ kN/m^3, $c' = 5$ kPa, and $\phi' = 27°$, (b): $\gamma_t = 13$ kN/m^3, $c' = 22$ kPa, and $\phi' = 32°$, (c): $\gamma_t = 16$ kN/m^3, $c' = 29$ kPa, and $\phi' = 18°$, and (d): $\gamma_t = 18$ kN/m^3, $c' = 8$ kPa, $\phi' = 20°$).

Table 2
Errors due to changes in upstream water level and soil properties.

Upstream water level (m)	Error (%)			
	Fig. 14(a)	Fig. 14(b)	Fig. 14(c)	Fig. 14(d)
0	0.21	0.06	0.12	0.15
2	0.21	0.22	0.04	0.15
4	0.21	1.00	0.46	0.53
6	0.48	1.01	1.26	0.86
8	1.86	1.79	1.07	1.68

analysis was obtained from ChatGPT by simple prompt in this study. This implies that the effective methodology can be adopted even though the user does not know the detailed methodology for the given governing equation. In addition, the total hydraulic head throughout the domain was easily converted to the pore water pressure by using a simple prompt (e.g., calculate and plot pore water pressure in the code for seepage analysis), which indicates that ChatGPT more or less remembered the overall content of prompt history.

The results shown in this study also indicate that the coupling of seepage and slope stability analysis can be easily achieved by ChatGPT. In addition, the calculated FoS as a function of upstream water level shown in Fig. 14 implies that the sensitivity analysis of the model can be easily performed using ChatGPT. Although the one-way coupling using static seepage analysis results was performed in this study, the transient fully coupled analysis may be achieved using a similar prompt shown in this study. Because the seepage-induced slope stability is mostly related

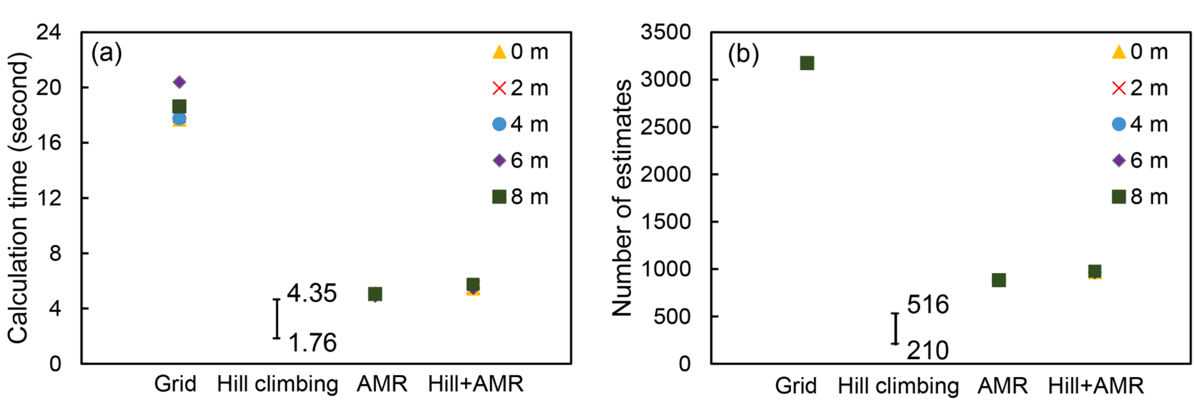

Fig. 15. Calculation time ((a)) and number of estimates ((b)) for grid search, hill climbing, AMR, and AMR combined with hill climbing for upstream water level = 0, 2, 4, 6, and 8 m (Type 2 slope).

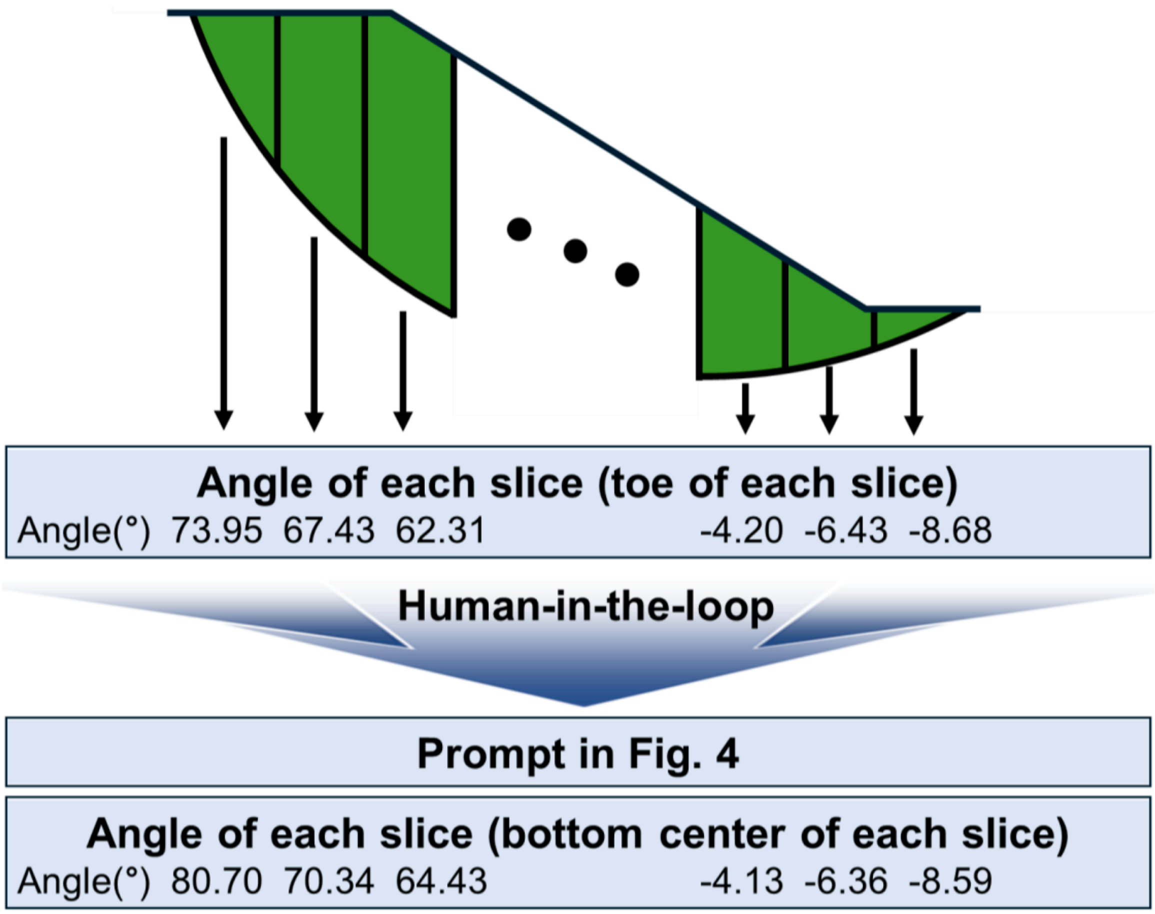

Fig. 16. Schematic illustration of human-in-the-loop process for revising slope angle of each slice.

to rainfall intensity in the real-world problem, transient fully coupled analysis can provide the robust framework with high applicability. The fully coupled analysis requires the update of FoS by transient flow in each time step, even more elaborate prompts than those used in this study can be anticipated.

When combining seepage analysis results with slope stability analysis, ChatGPT failed to recognize the phreatic line properly on the first attempt, in which ChatGPT was prompted to extract the phreatic line before applying it to slope stability analysis. The second attempt successfully returned the results shown in Fig. 13 by numerically identifying the phreatic line at an interval of 0.1 m by applying the uniform line segmentation method in the prompt. This indicates that a human-in-the-loop process (Zanzotto, 2019; Wu et al., 2022) is still required for the proper application of ChatGPT for seepage-induced slope stability analysis. Nevertheless, the successful implementation of the coupling process may not be required to provide identical prompts as the ChatGPT remembered previous prompts for the coupling process. Overall, the framework and results shown in this study imply the chance of applying ChatGPT in seepage-induced slope stability problems. In particular, the application of FEM-based framework using ChatGPT for consolidation problem (Kim et al., 2025) demonstrated that the chance for developing the FEM-based seepage-induced slope stability using ChatGPT.

The limitations of Bishop's method include the assumption of circular failure surface, which cannot simulate slope failure with unknown failure surface (e.g., localized slope failure). Therefore, the development of framework for FEM-based slope stability using ChatGPT can provide the wide applicability of ChatGPT for slope stability problems. The Mohr-Coulomb failure criterion can apply to the whole domain in the software such as ABAQUS (Cao and Go, 2024; Paknahad et al., 2021; Ho, 2014; Setiawan and Kim, 2025), which can be used for comparison with the results obtained from ChatGPT. In addition, this study focuses on two-dimensional steady-state analysis, the transient and three-dimensional analyses are beyond the scope of this study.

4. Conclusion

This study investigated the application of ChatGPT on seepage-induced slope stability analysis. The obtained FoS by ChatGPT was validated using those from SLOPE/W and SEEP/W. Based on the results obtained in this study for two types of slopes, the following conclusions can be drawn:

1) The error of FoS values between ChatGPT and SLOPE/W for seepage-induced slope stability was less than 1.86% for all scenarios, indicating the chance of using ChatGPT for Bishop's method-based seepage-induced slope stability.
2) The implementation of seepage-induced slope stability can be achieved using ChatGPT without providing mathematical expressions of Bishop's method and optimization methods.
3) The best-performing optimization techniques of AMR combined with the hill climbing method and hill-climbing method for Type 1 and Type 2 slopes shown in this study indicate the geometry-dependent optimization methods for seepage-induced slope stability analysis. Notably, the use of these optimization techniques enabled up to a 70% reduction in calculation time compared to the grid search method.
4) The multiple trials for coupling by prompting the uniform line segmentation method with an interval of 0.1 m and extracting bottom center points of slices for slope stability analysis indicate that some

degree of the human-in-the-loop process would be required to obtain successful implementation of seepage-induced slope stability analysis using ChatGPT.

5) The errors of FoS shown in this study are likely attributed to the FDM-based seepage analysis in ChatGPT. Further development for FEM-based seepage analysis using ChatGPT would be required to minimize the errors.

CRediT authorship contribution statement

Junhyeok Kwak: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Jongmuk Won:** Writing – review & editing, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.kscej.2025.100457.

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