Machine Learning in a Retaining Wall Design

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***Abstract*—**Currently, numerical modelling in geotechnical engineering is both prevalent and sophisticated. Many advanced input settings and significant computational efforts are necessary to optimize the design to reduce construction costs. Optimizing a design typically requires numerous numerical modelling trials. Manual optimization involves significant time spent on creating model inputs and extracting data from outputs with potential for high risk of introducing human errors due to repetitive tasks. This paper presents an automation process for analyzing the entire secant-pile retaining structure in an underpass project. Python and Visual Basic for Applications scripts are utilized to control the whole process. Numerical models (PLAXIS2D) are set up automatically every 20 m along the 270 m underpass. The automation process continuously alters the geological stratum and retained height while creating each design section at 20 m intervals. For each design section, trial and error calculations are automatically performed to determine the required pile length. The use of a prop system is automatically activated when the deflection limit is exceeded. This paper provides insight into how automation can be integrated into the entire geotechnical design through a case study. Results show that automation significantly reduces design time and increases the number of assessed scenarios, which increases overall efficiency and confidence. It also minimizes and prevents errors, and thanks to the high number of combinations in sensitivity analyses, it lowers the associated risks to levels that manual operations would struggle to achieve.

***Keywords*—**Automation, numerical modelling, Python, retaining structures.

I. INTRODUCTION

AN artificial intelligence (AI) system utilizing Python and Visual Basic for Applications (VBA) has been developed to automate the design of a secant pile retaining wall. This system controls the numerical Finite Element (FE) analyses in PLAXIS2D and generates graphical interpretations in EXCEL. It automatically imports the underpass and subsoil profiles from EXCEL and sets up the design cross-sectional models at 20m chainage intervals in PLAXIS2D. In each design section, numerical analyses are performed iteratively until an optimal solution is achieved that satisfies the project stability and deflection criteria. This process is repeated for the entire retaining wall.

II. RECENT AUTOMATION IN GEOTECHNICAL ENGINEERING

Over the past decade, automation supported by machine learning and AI has gained increasing significance in geotechnical engineering. For example, [2] utilized VBA to optimize the base length of an L-section retaining wall. Reference [5] demonstrated the application of Python in various geotechnical tasks, classifying its uses into calculators, data handlers, and visualizers. Reference [4] employed Python scripts to simulate the phi-c reduction method for the stability of a slope section and automatically adjust pile sizes to identify critical diameters for different soil friction angles. Reference [6] presented an automated method to convert Cone Penetration Test (CPT) readings into Soil Behavior Types (SBT), facilitating the creation of necessary input parameters for finite element modeling. Reference [7] investigated the integration of AI and the Internet of Things (IoT) for site characterization. Furthermore, [8] explored how generative AI can be incorporated into numerical analysis workflows for geotechnical engineering designs, using large language models and platforms like ChatGPT as virtual assistants to convert PLAXIS commands into Python scripts, thus enhancing their functionality for automation. Even with these advancements, there is still limited demonstration of fully integrating automation into the design of complete geotechnical structures. This paper offers insights into utilizing automation in the geotechnical analysis of a complete retaining structure.

III. PROJECT DESCRIPTION

A new underpass, supported by secant pile retaining walls, has been constructed in Southeast Queensland. This underpass spans over an approximately 300 m and features open ramps at both ends to ensure adequate headroom. The central section is enclosed by a top slab, with a maximum retained height of about 6 m, facilitating traffic above. To meet the targeted ground settlement and wall deflection, Circular Hollow Section (CHS) steel props were installed at the entry and exit points of the covered area. Construction began with the secant pile walls, followed by the installation of the top slab and CHS in the central section. Excavation work commenced on the ramps and gradually progressed toward the deepest point in the center. Figs. 1 and 2 illustrate the longitudinal profile and typical section of the underpass.

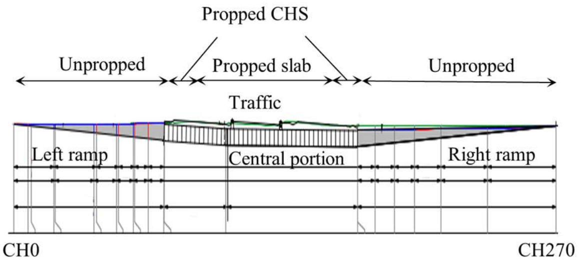

Fig. 1 Underpass longitudinal profile

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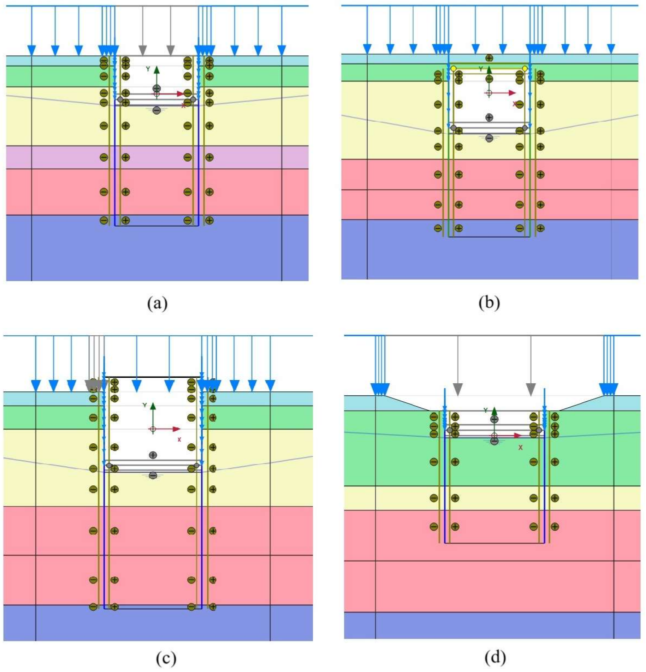

Fig. 2 (a) CH0 to 70; (b) CH100 to 180; (c) CH70 to 100 & CH180 to 220; (d) CH220 to 270

IV. GROUND PROFILE DESCRIPTION

The ground profile consists of approximately 2 m of medium-dense sand overlaying about 5 m of indurated dense silty sand. Loose and medium-dense sand layers underlie the indurated sand layer, followed by a stiff silty/sandy clay layer. The groundwater level is roughly at the ground level. The ground subsoil profile is presented in Fig. 3. The adopted design parameters are detailed in Table I.

TABLE I
GEOLOGICAL UNITS

Geological Units	Cohesion, c' (kPa)	Friction Angle, ϕ' (°)	Young's Modulus, E (MPa)
Fill	0	28.5	22.5
Upper sand	0	30	35
Indurated dense sand	10	38	80
Loose sand	0	26	7.5
Lower sand	0	30	35
Stiff silty/sandy clay	5	28	40

V. METHODOLOGY

The automation process is divided into two stages: Stage 1: stability and displacement analyses to obtain the optimal solution for the wall length, and Stage 2: generating structural forces for the structural design.

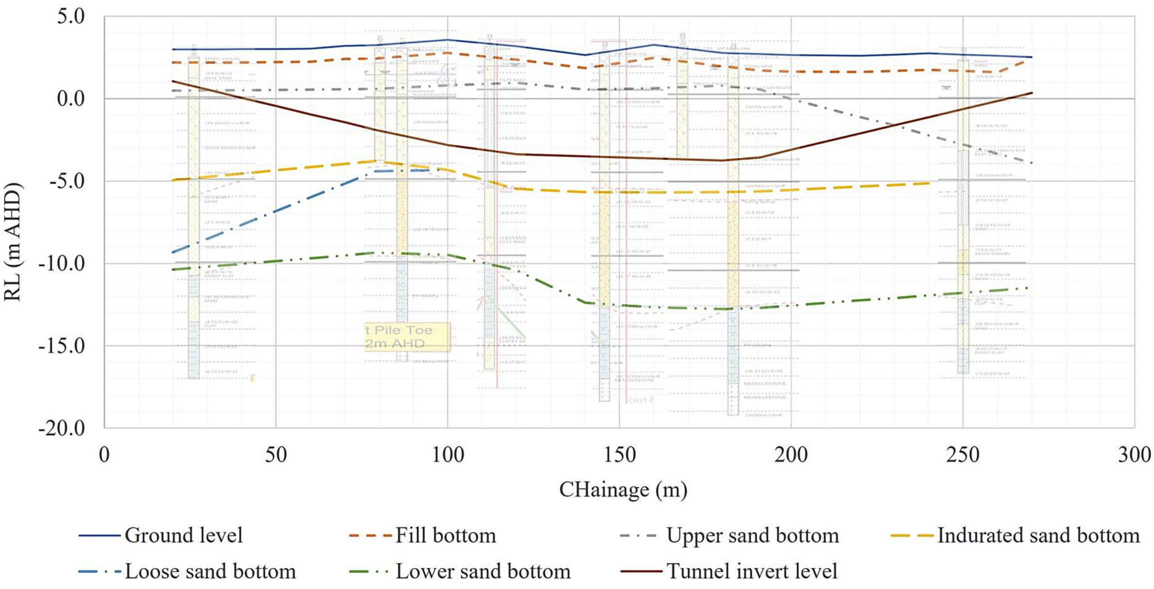

Fig. 3 Ground subsoil profile

A. Stage 1: Stability and Displacement Analyses

The longitudinal profile of the underpass and the subsoil depths of discrete boreholes are pre-defined in EXCEL. In each design section, Python scripts extract and interpolate the aforementioned data from EXCEL to create the cross-section model in PLAXIS2D. It then manages the entire PLAXIS2D setup and analysis. Long-term drained steady-state flow analysis is adapted in the analysis. Initially, the length of the retaining wall is estimated based on the suggested ratio of wall length (H) to retained height (h) from [1] to initiate the analysis. The H/h ratios for the propped and unpropped sections under varied soil and wall friction angles from [1] are digitized into equations (as shown in Figs. 4 and 5). An average strength value of the soils along the wall length is used to determine the initial H/h ratio from Figs. 4 and 5.

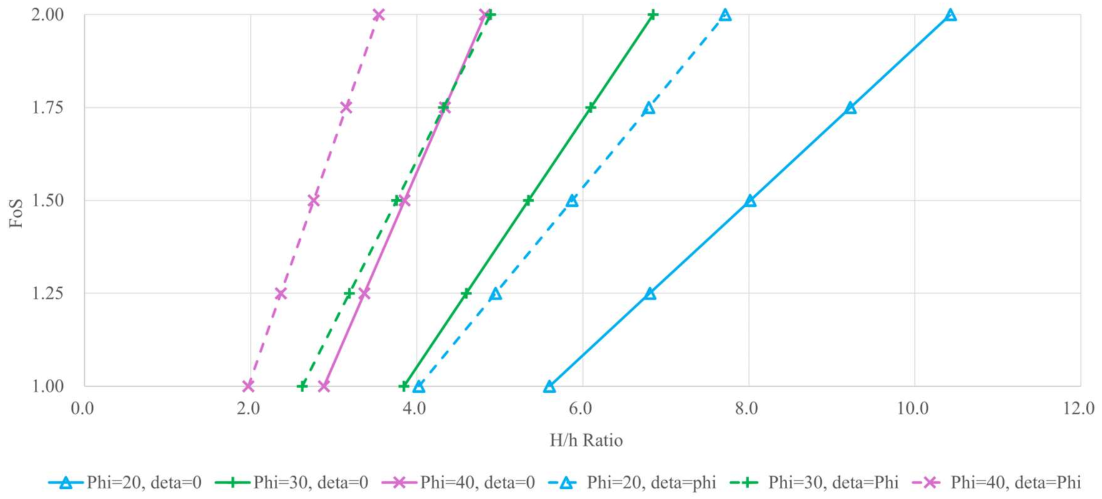

Fig. 4 Suggested wall length to retained height (H/h) ratio for the unpropped section in [1]

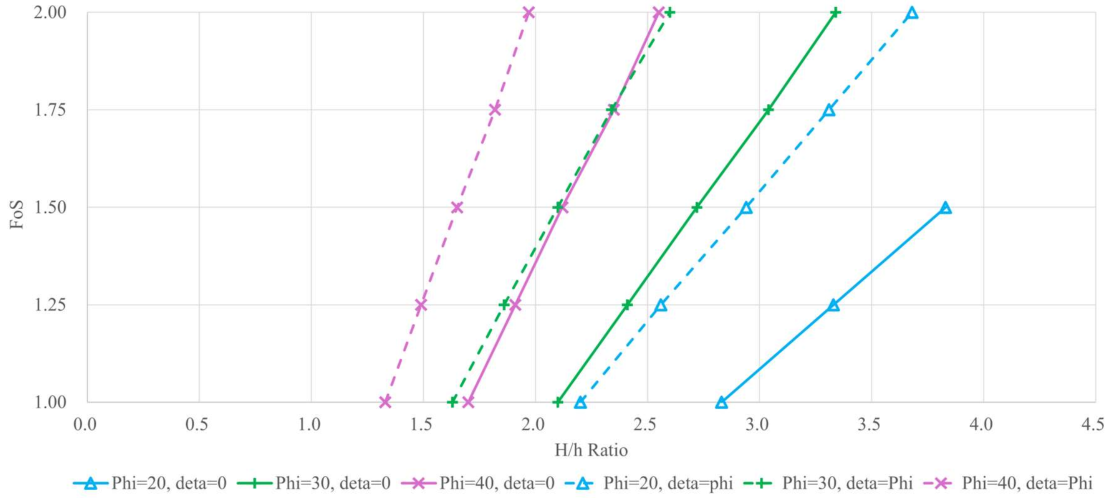

Fig. 5 Suggested wall length to retained height (H/h) ratio for the propped section in [1]

After an initial trial analysis, Python scripts retrieve the calculated Factor of Safety (FoS) and displacement results from PLAXIS2D analysis. If the FoS exceeds the target maximum of 2.0, the pile penetration will automatically decrease by 5% to proceed to the next iteration. However, if the FoS is lower than the target minimum of 1.5, the pile penetration will increase by 10% in the next run (using different percentages to prevent oscillation between two ratios and avoid failing to converge).

If there are more than two iterations done, interpolation based on the previous two iterations is used to project the H/h ratio at FoS = 1.5 to speed up the calculation. This process will continue until the calculated FoS converges to the target range (1.5- 2.0). Meanwhile, if the maximum ground settlement behind the wall and the wall deflection exceeds the target limit, a steel CHS prop is automatically added, and a new iteration will restart using the estimated H/h ratio of the propped section in Fig. 5 to shorten the wall length for design optimization. The process also checks whether there is sufficient headroom. If not, it will raise the prop to the level matching adjacent chainages (for symmetrical appearance). All the iteration results are collected throughout the process to feed back into the centralized database to update the project-specified H/h ratios and improve the AI procedure. The automation design process is summarized in Fig. 6.

B. Stage 2: Generating the Structural Force for Structural Design

After obtaining the optimal wall length during Stage 1 automation, graphical plots of the wall bending moment (BM) and shear force (SF) are automatically generated in Excel for structural design. However, this stage provides an additional option to conduct a sensitivity analysis to investigate input parameters that significantly impact structural forces. In the process, Python scripts extract the PLAXIS model data and send it to Excel. This allows designers to select the range (lower and upper bound values) of the selected input parameters for the sensitivity analysis. The selected range will be fed back by Python scripts into PLAXIS for further analyses. In this project, it was predicted that the soil moduli (upper sand, indurated sand, lower sand, and the bottom clay layers) and the over-consolidated ratio (OCR) of the indurated sand could vary much across the site. Therefore, these parameters are selected for investigation. Each selected parameter will have lower bound, average, and upper bound values, with 3^n combinations (where n is the number of selected input parameters) for the sensitivity analysis. This sensitivity analysis includes approximately 240 cases. Fig. 7 summarizes the Stage 2 automation process.

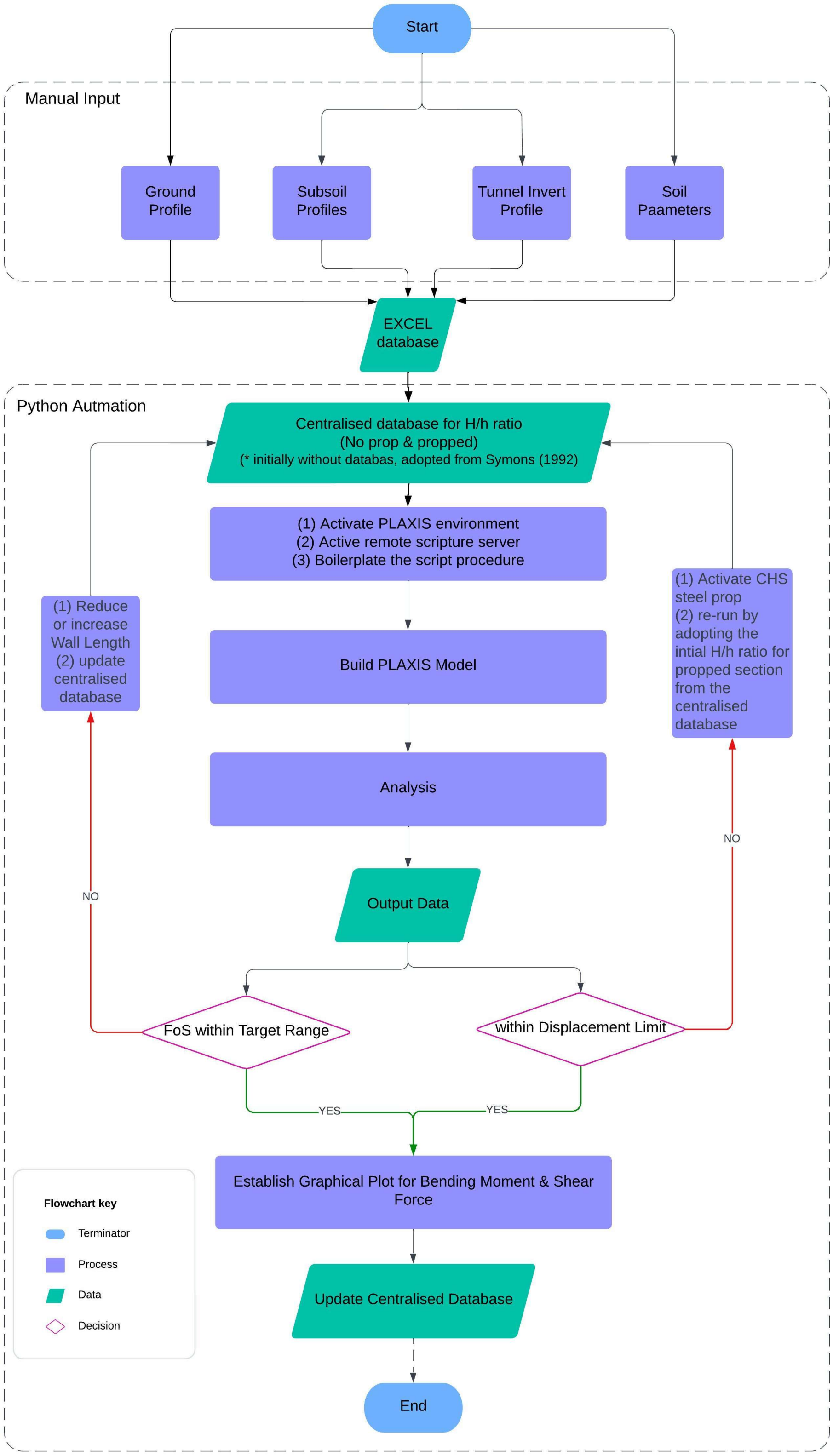

Fig. 6 Stage 1 automation algorithm

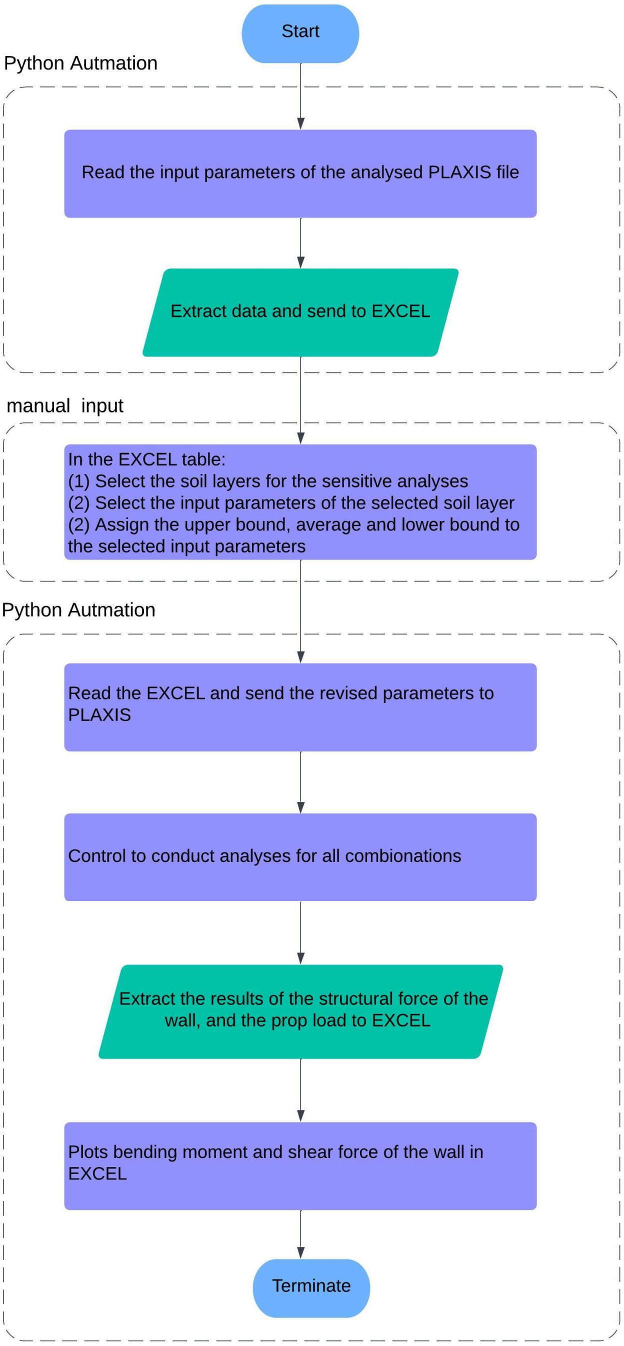

Fig. 7 Stage 2 automation algorithm

VI. RESULTS

A. Updated the H/h Ratio in the Centralized Database

Figs. 8 and 9 present the updated centralized database for no-prop and propped sections. The project-specified H/h ratio correlating with the average strength for the propped section aligns well with [1]. Therefore, the automation process continues to utilize the ratio from [1]. However, there is a modification factor of 0.7 from [1], which has been updated in the project-specified centralized database.

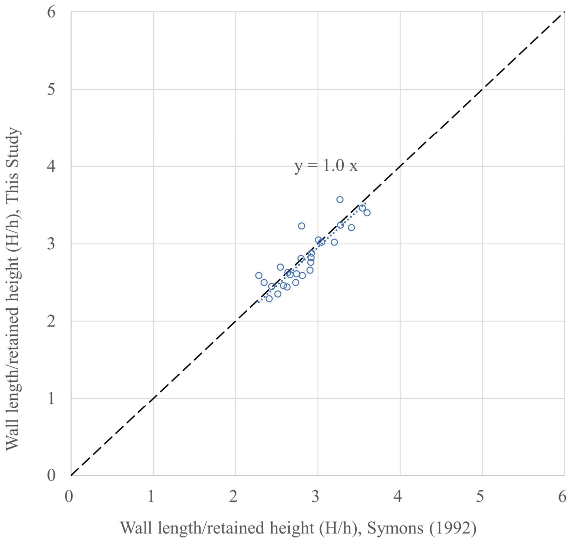

Fig. 8 Updated database for the propped section

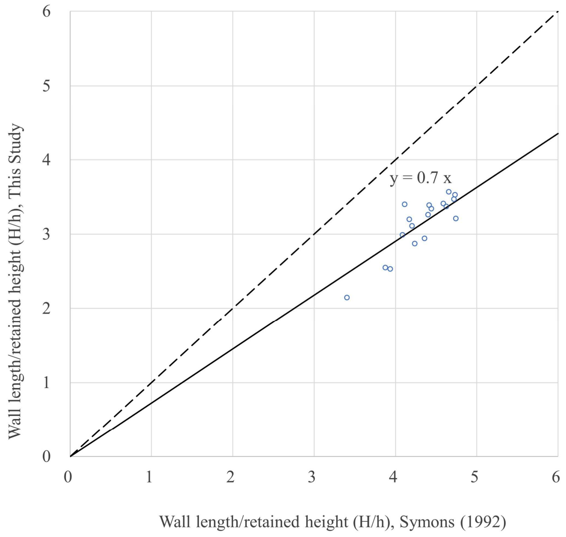

Fig. 9 Updated database for the unpropped section

B. Wall Length from Stage 1 Automation

Fig. 10 presents the optimized wall length by the automation process with FoS between 1.5 and 2.0. Lateral supports (CHS props and top slab) are required to limit the ground settlement between CH70 and CH200.

C. Sensitivity Analysis for Structural Design in Stage 2 Automation

The possible ranges for the selected parameters in the sensitivity study are summarized in Table II.

TABLE II
SELECTED PARAMETER AND RANGE FOR ANALYSIS

Selected Parameters	Lower Bound	Average	Upper Bound
OCR of Indurated Sand	1	2.5	5
Modulus of Upper Sand (MPa)	10	35	70
Modulus of Indurated Sand (MPa)	20	80	160
Modulus of Lower Sand (MPa)	10	35	70
Modulus of Lower clay (MPa)	10	40	80

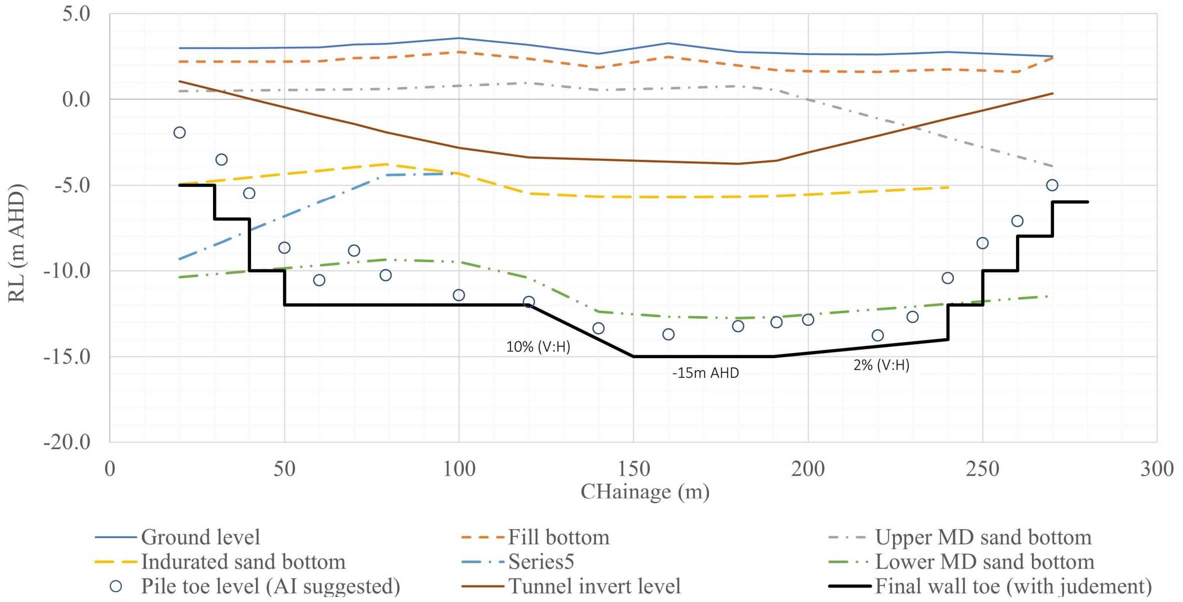

Fig. 10 The optimized wall length from the automation process

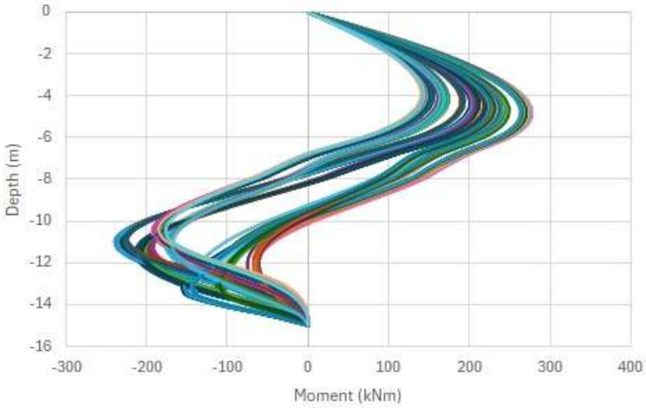

Fig. 11 Wall bending moment within the possible ranges of the parameters in the sensitivity analysis

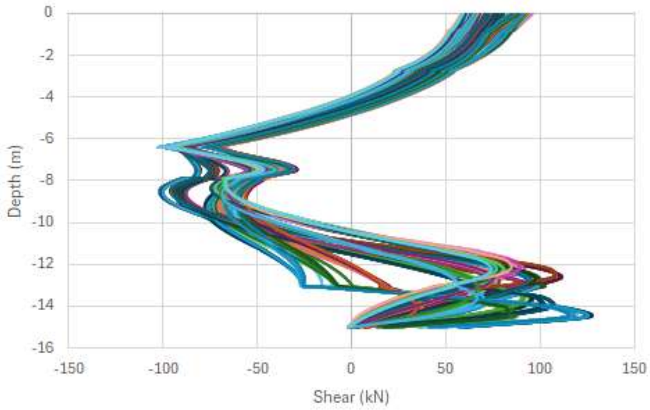

Fig. 12 Wall shear force within the possible ranges of the parameters in the sensitivity analysis

Figs. 11 and 12 present the sensitivity study results over 240 combinations within the range of the selected input parameters. The results show that changes in the OCR within the possible range of the indurated sand do not significantly impact the structural force of the retaining wall. However, a higher modulus in the passive zone (the wall embedment portion) combined with a lower modulus in the active zone (the retained soil portion) will produce approximately a 90% increase in the wall bending moment and a 50 % increase in shear force compared to the case using average values.

VII. CONCLUSION

An automation process was employed to optimize the design of a retaining wall in an underpass project. It showcases the ability to automatically develop cross-section models for geotechnical analysis along the entire wall. This automation process can perform a high number of trials to enhance the design to a level and efficiency difficult to achieve with a manual approach. The underpass alignment was revised several times, and automation can deliver efficient design output to accommodate the change. Automation reduces design time and construction costs while increasing confidence in the results and eliminating human error. The benefits are significant, especially for extensive long embankment and retaining wall projects.

Thanks to the sensitivity assessment carried out on a large number of scenarios, the study shows that soil modulus parameters could significantly impact the structural force of a retaining wall. However, moduli can vary considerably across chainage, especially for long structures within the kilometer range. A sensitivity analysis is highly recommended to acknowledge this impact in the design.

However, not all engineers are familiar with scripting languages, which presents a potential challenge to setting up automation. To further enhance user-friendliness in the automation procedure, it is recommended to implement a platform that includes pre-defined “sub-section” scripts, making it easier for engineers to drag and assemble the entire automation script. Generative AI can be incorporated into the platform to enable engineers to inquire about converting their ideas into automation scripts. We anticipate a more mature and collaborative platform integrating the most common computer software to connect design processes among geotechnical, structural, and civil engineering engineers.

Aligned with [3] and [5], automation is intended to support repetitive tasks rather than replace human judgment. Engineering judgments are essential inputs that guide the direction of automation, predict calculation trends, and interpret the final results.

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