Solution for Geotechnical Data Platform and BIM-based Foundation Design Automation

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ABSTRACT

This paper introduces two automated tools developed by the author for foundation engineering: GI_Inventory, a geotechnical data integration platform, and ETE_Foundation, an automated foundation design tool. Leveraging geotechnical public data from the Hong Kong Common Spatial Data Infrastructure (CSDI), including geotechnical borehole locations and AGS files, the author developed GI_Inventory—a GI data platform. The software automates the retrieval and organization of AGS documents for Hong Kong, generates geotechnical data tables and drawings programmatically, the author developed ETE_Foundation, an automated tool for pile foundation design. Engineers can establish pile foundation analysis models based on BIM models and geotechnical data. ETE_Foundation automatically generates models and conduct analysis and design for pile foundations. The tool integrates geotechnical data, enabling automatic calculation of pile lengths and adjustment of soil spring parameters in the model. This facilitates rapid design results for piles, accommodating changes and modifications in engineering design. Overall, these automation tools, GI_Inventory and ETE_Foundation, streamline foundation engineering processes by automating geotechnical data integration, organization, retrieval, and analysis. They enhance efficiency, accuracy, and adaptability in foundation engineering projects.

1 INTRODUCTION

The main content of this article is to introduce two automated tools developed by the author for foundation engineering: the geotechnical data integration platform, GI_Inventory, and the automated foundation design tool, ETE_Foundation. Based on the geotechnical public data provided by Hong Kong Common Spatial Data Infrastructure (CSDI), including the planar locations of geotechnical boreholes and digital documents of geotechnical data (AGS documents), the author developed a comprehensive geotechnical data application platform called GI_Inventory. This article describes the implementation method of the software and the functionalities that have been completed so far, including the automated retrieval and organization of AGS documents provided by CSDI for the entire Hong Kong region, the generation of geotechnical data tables and drawings through programming, and the creation of CAD drawings and BIM models using geotechnical data.

The author also developed the automated foundation design tool, ETE_Foundation. Engineers can establish pile foundation analysis models with geotechnical data based on BIM models. Through finite element calculations, the tool automatically generates models and performs analysis and design for pile foundations. The automated program for pile foundation design integrates geotechnical data and can automatically calculate pile lengths and adjust soil spring parameters in the model, providing quick design results for piles. The high level of automation in the entire pile foundation design process accommodates inevitable changes and modifications in engineering design.

2 THE DEVELOPMENT OF GI_INVENTORY

2.1 Conventional Approach

The traditional workflow for using geotechnical data involves querying borehole data from the Geotechnical information infrastructure (GeoInfo) website for the vicinity of a project site. Then, based on the GeoInfo

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index, relevant site reports or laboratory reports in PDF format are searched and downloaded. Subsequently, geotechnical engineers analyze and process the data.

In addition to providing PDF documents, both CSDI and GeoInfo also offer corresponding AGS data files. AGS data is a standardized digital format introduced by GEO in 1993 and published by the Association of Geotechnical and Geo-environmental Specialists (AGS). Similar AGS data requirements are also adopted in most government geotechnical investigation contracts.

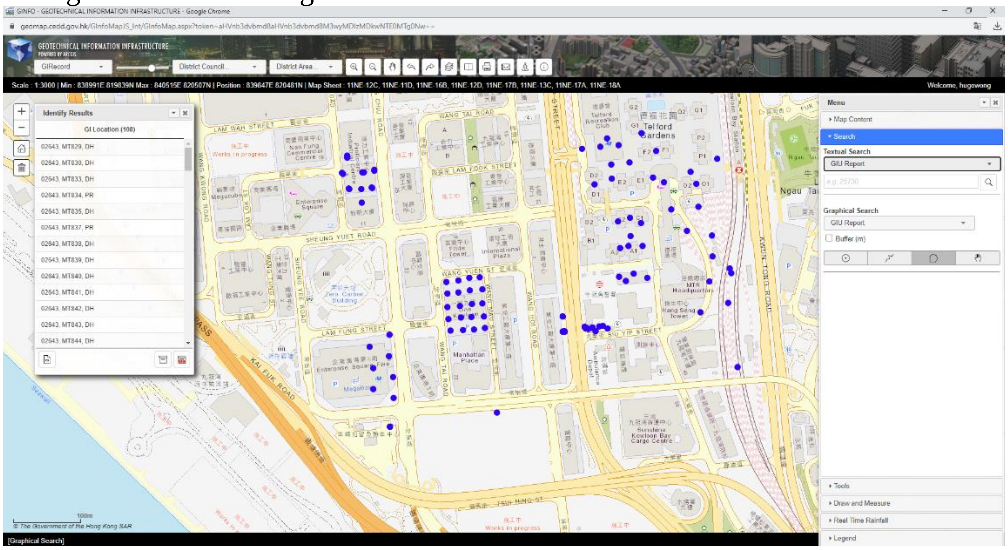

Figure 1: GeoInfo website user interface

Currently, the GeoInfo website only provides download links for AGS data documents of the respective boreholes, without integrating detailed AGS data into the GeoInfo platform for users to search through webpages. The current procedure involves downloading relevant AGS files or PDF documents and manually organizing the geotechnical information by engineers. This entire process requires significant data processing time and does not utilize the existing AGS data files.

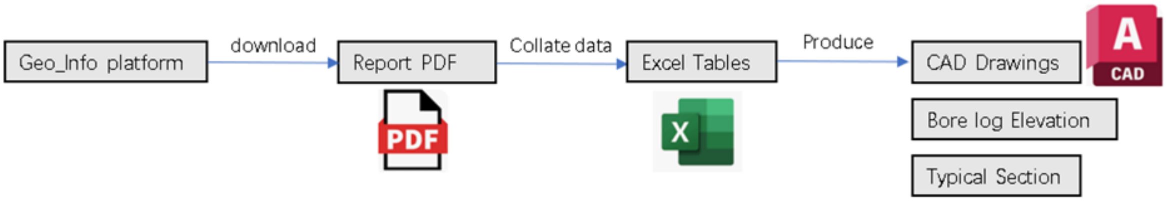

Figure 2: The traditional workflow for handling GI Data

After organizing the geotechnical information, As shown in Figure 2, engineers determine different soil or rock layer types, elevations, and thicknesses through textual descriptions of the geotechnical layers. They then convey this information to draftsmen for the preparation of geotechnical plan drawings, rock head contours, and profiles of critical sections. Alternatively, engineers can establish a Civil3D model to create relevant profiles, which can be used by foundation design engineers.

2.2 Problem Statement

To address the aforementioned challenges and make the entire process more intelligent, the author of this paper aims to integrate data from the AGS digital files provided by CSDI and establish a comprehensive geotechnical data platform called GI Inventory. This platform enables engineers to directly access and apply geotechnical data in foundation design. Within GI Inventory, engineers can obtain information such as the planar location, type, and depth of borehole, classification and elevations of geotechnical layers, and relevant laboratory data (e.g., Triaxial Test data), as shown as Figure 3. GI Inventory can directly generate AutoCAD drawings, including plan views and cross-sectional views of the boreholes. Additionally, it can generate a

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BIM model of the geotechnical data (based on the Revit platform) for engineers to coordinate and use collaboratively.

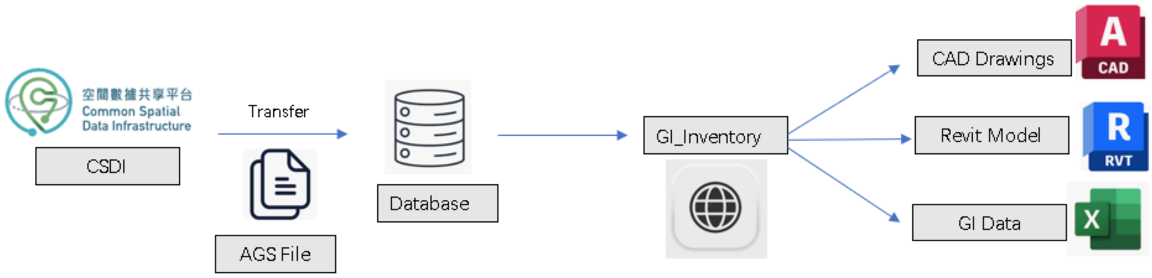

Figure 3 The design concept of GI_Inventory for extracting GI Data

During the development of the comprehensive geotechnical data platform GI Inventory, the following challenges are encountered:

Using AGS files to process geotechnical data does come with some challenges. One problem is the compatibility issue between AGS files and existing software or systems. Not all geotechnical software applications or databases are designed to handle AGS files seamlessly. This can create difficulties in importing and manipulating the data, potentially leading to errors or incomplete analysis. Another issue is the lack of uniformity in AGS file formats. While AGS is a standardized format, there can be variations in how different organizations or software vendors implement it. This can result in inconsistencies in data interpretation and compatibility issues when exchanging AGS files between different systems or projects. Furthermore, AGS files may not always capture all the necessary information or details required for comprehensive geotechnical analysis. Some critical data points or parameters may be missing or not adequately represented in AGS files, limiting the accuracy and reliability of the analysis.

The complete set of AGS files provided by CSDI consists of two types of data: site data and laboratory data. However, CSDI has not classified these two types of data nor provided any information on their interrelationships. In order to establish the correlation between the two, it is necessary to employ artificial intelligence to carry out the analysis, e.g. project names in the AGS files. Additionally, a comprehensive evaluation can be conducted by taking into account the boreholes names, which will aid in determining the association between the two types of data.

2.3 Digital Solutions

One of the key technical challenges in developing a comprehensive geotechnical data platform is determining the category of a geotechnical layer based on the textual description in the AGS. After obtaining the attribute descriptions of soil layers and the grading of rock layers from the AGS, a preliminary classification is performed using a specific mechanism. However, even after the preliminary classification, there are still some cases where the category of a layer cannot be uniquely determined based solely on the text and grading. These cases are initially marked as "unknown" types. For a subset of samples, engineers use their expertise to identify the layers, and these manually identified results are used to train an AI model. Eventually, a geotechnical layer classification with a certain level of accuracy is achieved.

For example, Lithology essentially classifies materials into two groups: solid geology and superficial deposits. Superficial deposits primarily describe the type of soil, such as fill, alluvium, or marine deposits. Solid geology, on the other hand, describes the type of rock, including tuff, granite, granodiorite, quartz monzonite, and more. However, merely identifying the material type is not sufficient for lithology; it should also encompass the size of the materials. Soil, for instance, can be classified into various sizes, including gravel, sand, clay, silt, cobble, and boulder. Rocks, on the other hand, can be characterized by their degree of decomposition, such as completely decomposed, slightly decomposed, or fresh. To extract the relevant information from the description sentence, we need to identify and extract the following elements: capital letters, words enclosed in brackets, and the degree of decomposition level.

The AGS files provided by CSDI do not explicitly indicate the relationship between site reports and laboratory reports. The laboratory reports only specify the names of different boreholes without providing the plan coordinates of the boreholes. As a result, the CSDI platform does not display the positions of laboratory reports in relation to the boreholes. The only way to determine the relationship between laboratory reports and site reports is by matching the project names and borehole names in both reports. The names of laboratory reports associated with site reports are shown in Figure 4. The pairing of project names requires the use of artificial intelligence for approximate string comparison and scoring. By combining the results of borehole pairing, the corresponding relationship between the two can be determined.

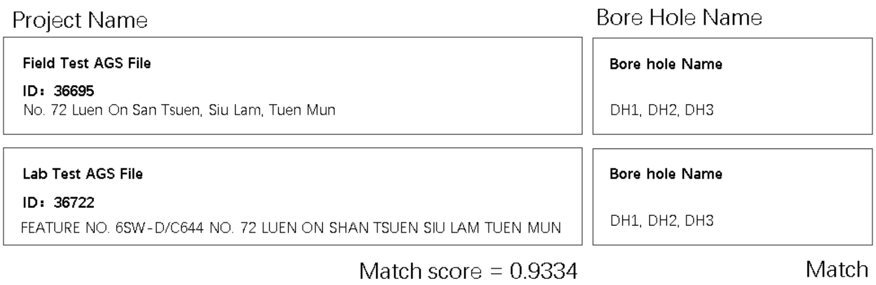

Figure 4. To compare and find the relationship between two AGS Files

GI_Inventory is a form-based program developed on the Delphi platform, as shown as Figure 5. The program organizes a large amount of geotechnical data from AGS files into a database format using Python scripts. The GI_Inventory program is called directly in the background and does not require re-identification or computation. As indicated in the diagram below, the program reads the database, and users can select the area of interest by drawing a box. The program automatically displays the relevant boreholes. By clicking on "Show Selected GI Data," users can access the next-level form. In this form, users can query spatial information and geotechnical data for all boreholes within the selected area. They can also view the project numbers and directly download the source AGS files. Users can also directly view the geotechnical data for specific boreholes associated with a specified Project_ID.

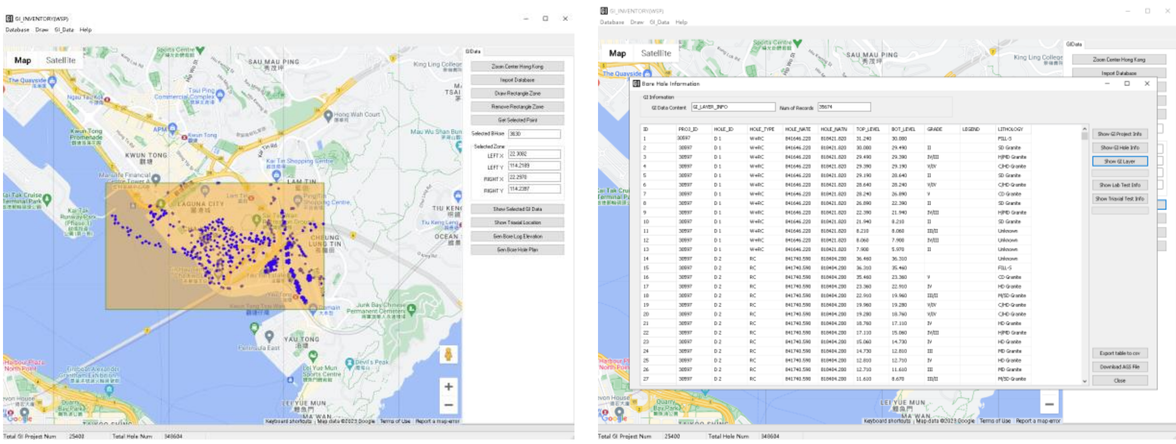

Figure 5. Graphical User Interface (GUI) of GI_Inventory

GI_Inventory has also been developed for post-processing. After selecting the desired data for querying, users can click on "Gen Bore Log Elevation" and "Gen Bore Hole Plan." Using ActiveX technology, the program generates CAD drawings through AutoCAD, creating borehole elevation and plan views, as shown in the diagram. These drawings are available for engineers to use, as shown as Figure 6.

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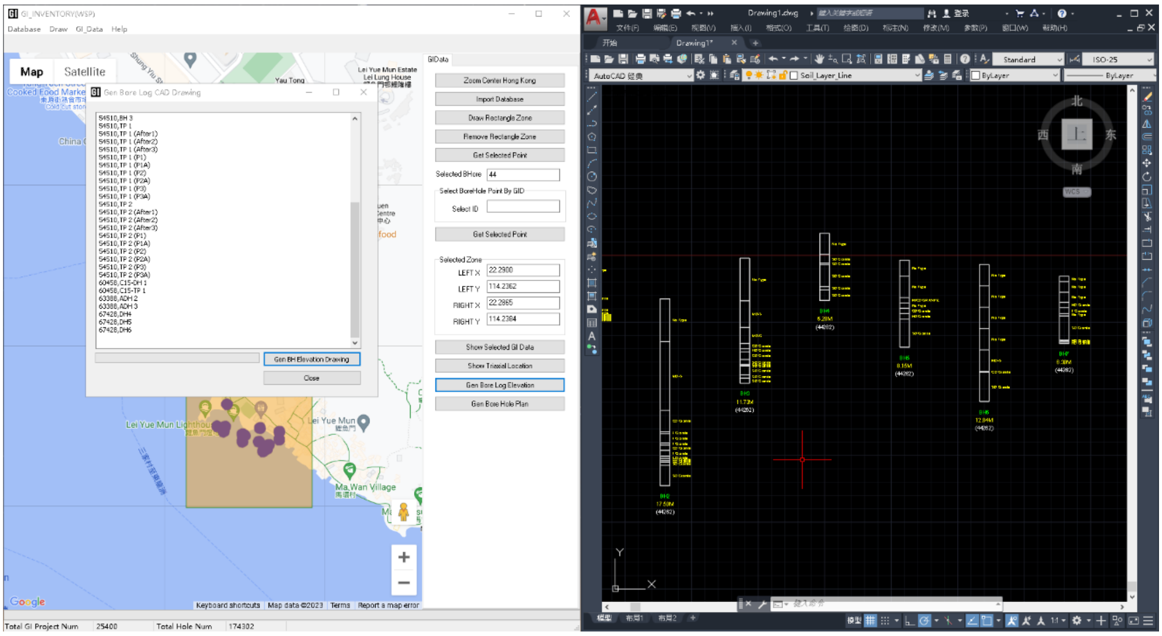

Figure 6. GI_Inventory generates bore log elevation drawings

3 FOUNDATION DESIGN PROGRAM ETE_FOUNDATION

3.1 Conventional Approach

In traditional foundation design methods, engineers are required to organize a large amount of geotechnical data and manually create the foundation model. The foundation model consists of four main components: piles and pile caps, loads on the superstructure, and soil linear springs. The length of the piles is influenced by the depth of the rock surface, while the parameters of the soil linear springs depend on the distribution and thickness of the soil layers. After conducting finite element analysis to determine internal forces, reinforcement calculations based on the internal forces of the piles are performed (which cannot be adequately handled by finite element analysis software alone, requiring additional reinforcement calculations). This is the complete process of pile foundation design, as shown as Figure 7. As design and geotechnical exploration work progress, the parameters need constant adjustment. This requires a significant amount of manpower and can lead to a decrease in accuracy. Sometimes, to save time on repetitive iterations, conservative values are used for certain geotechnical parameters, resulting in material waste during the design phase. The author of this paper aims to improve the efficiency of foundation design by developing a BIM-based foundation design software.

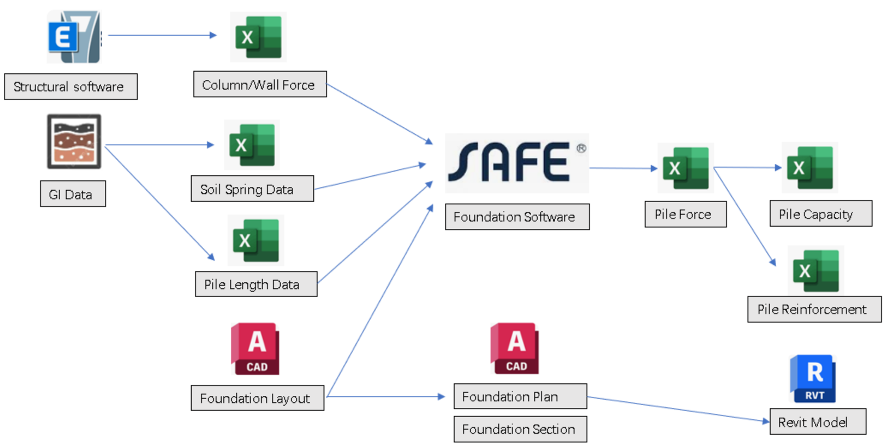

Figure 7. Traditional calculation processes for foundation analysis and design

3.2 Problem Statement

Currently, commercial software available on the market cannot handle the entire process of foundation design. When using software in conjunction with the foundation design process, the overall workflow is as shown in Figure 7. Throughout the foundation design process, which includes modeling, handling loads from the superstructure, pile reinforcement calculations, and pile bearing capacity verification, most of the steps require engineers to manually create Excel spreadsheets for calculations and batch processing.
Commercial software such as SAFE is only responsible for calculating the stress on the pile cap and the internal forces of the piles. Moreover, the modeling process in SAFE, which involves the concept of soil springs, is complex, and engineers often resort to using spreadsheets for batch processing. Therefore, in this article, the author proposes modeling the foundation model using a BIM-based platform, ensuring that most of the information can be imported into SAFE software, including geotechnical information. Additionally, BIM can assist engineers in generating CAD drawings, tables, and pile schedules during the post-processing phase.

3.3 Digital Solutions

GI_Inventory can assist engineers in gaining preliminary understanding of the geotechnical data near a project during the early stages. With GI_Inventory, elevation surfaces for multiple soil layers can be generated. The ETE_Foundation software can directly import the topological surface data of key soil layers, enabling the calculation of stiffness for all soil springs based on specifications. The geotechnical data provided by GI_Inventory can be used to preliminarily determine pile lengths. Based on engineering experience, the approximate cost range of the project can also be estimated. These preliminary assessments are of significant importance in the early stages of project planning and selection.

In order to enhance the digital application in the foundation design process, the entire foundation model is created using BIM technology. Since the foundation model includes piles, pile caps, soil springs, and loads from the superstructure, utilizing BIM modeling allows for the preservation of data within the foundation model. When there are updates in geotechnical information, the model can be instantly updated as well. Another benefit of BIM modeling is the ability to directly generate foundation plan layouts and cross-sections from the BIM model, reducing the workload of draftsmen. The workflow of ETE_Foundation is depicted in the Figure 8.

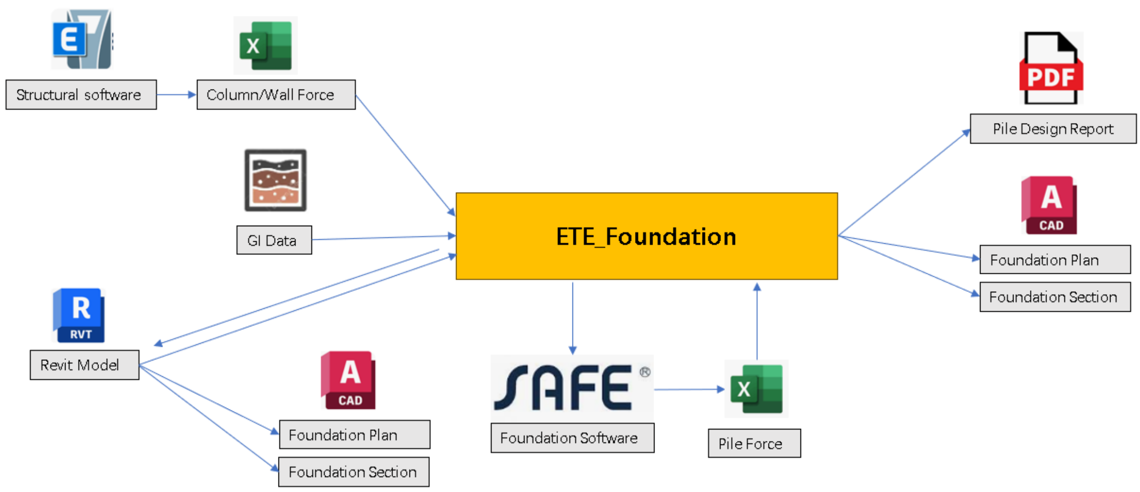

Figure 8. The design process of ETE_Foundation

The BIM-based foundation design software brings about the following innovations in the entire design process:

In the early stages, GI_Inventory provides borehole data that can be input into the ETE_Foundation software. The surface data of the rock layers can be imported into ETE_Foundation to determine the final pile length.

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The lateral stiffness of the soil springs is also related to the data of the soil layers. As shown in the Figure 9, automating the generation of pile spring properties can improve the efficiency of engineer modeling.

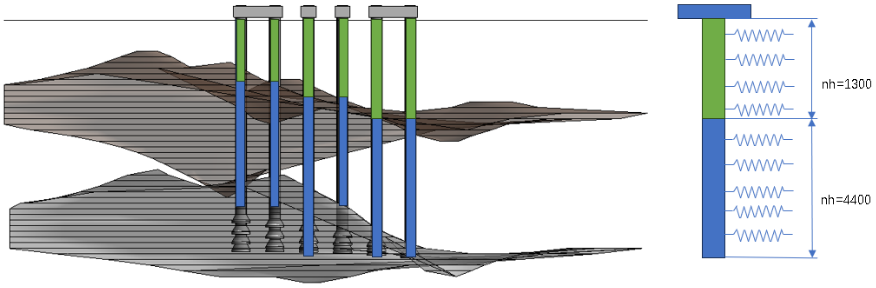

Figure 9. The relationship between soil layers and soil lateral springs

ETE_Foundation is a pile foundation design software based on the Revit model. This means that pile foundation can be created in Revit, including piles, pile caps, base slabs, rock layers, and more, all of which can be modeled in Revit, as shown as Figure 10. The model can then be imported into the ETE_Foundation for further processing and subsequently imported into the SAFE software for structural analysis. The interface of ETE_Foundation is shown in Figure 11.

After determining the soil spring parameters and pile length based on geotechnical data, the SAFE finite element model can be directly generated. Internal force analysis can be performed in the SAFE software. After the internal force analysis, users can import the internal force data into ETE_Foundation for reinforcement calculation of the piles and automatically generate calculation reports, as shown in Figure 12. ETE_Foundation uses the Load Fraction method for quick bearing capacity verification of bored pile reinforcement calculations. This method allows for a rapid assessment of whether the bearing capacity of the reinforcement section meets the requirements.

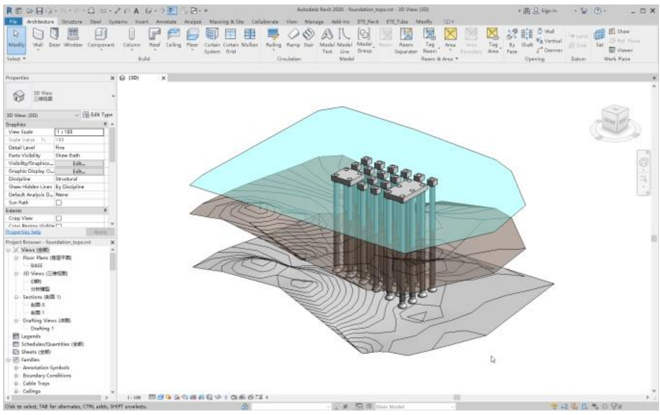

Figure 10. Foundation model in Revit

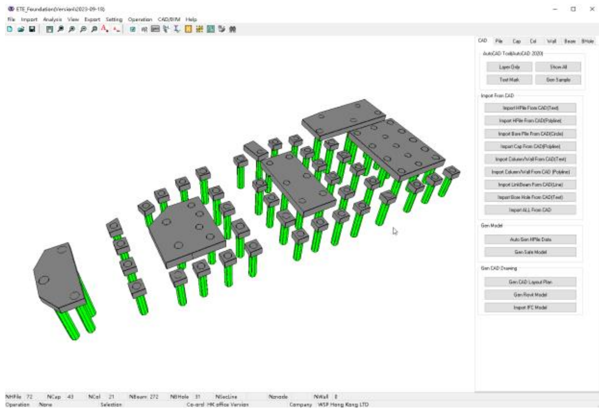

Figure 11. GUI of ETE_Foundation

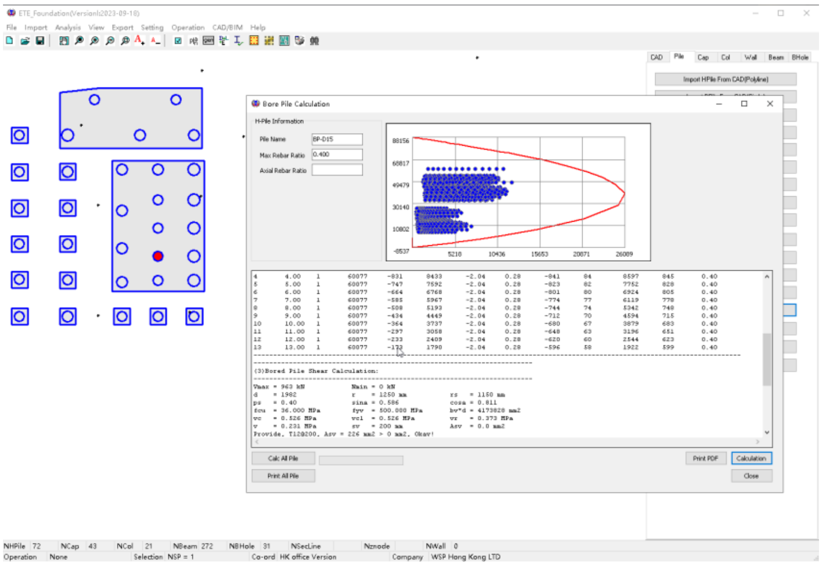

Figure 12. The reinforcement design function for pile foundations in ETE Foundation

4 CONCLUSIONS

The Development Bureau and the Lands Department launched the CSDI Platform on December 29th. The CSDI Platform provides a vast amount of geotechnical survey data for government infrastructure projects. In this article, the author utilized the AGS format files containing extensive geotechnical data provided by CSDI to develop the comprehensive geotechnical data platform, GI_Inventory. Unlike the GeoInfo platform, GI_Inventory directly extracts the contents of AGS data files, including borehole data, soil layer information, and laboratory data, reducing the time required for manual processing of geotechnical data. Additionally, the platform can generate borehole plan views and cross-sectional views, reducing the drafting time for draftsmen. The key surfaces generated by GI_Inventory can be imported into the foundation design software, ETE_Foundation, for foundation design. With the development of digital solutions and BIM technology, more and more projects are incorporating BIM technology. However, there is currently no integrated foundation design software based on BIM technology. This article discusses the traditional foundation design process and proposes a new digital solution tailored for foundation design. The software, ETE_Foundation, has been developed, allowing engineers to establish accurate BIM models, enabling subsequent design and analysis work to adapt to changes in the data model, meeting the requirements for continuous modification and updating in practical engineering projects. The entire digital workflow reduces manual processing time and errors.

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