A Case Study On The Predictive And Prescriptive Analytics In Underground Space Structures

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Abstract— *This piece of research aims to carry out a case study on predictive and prescriptive analytics in underground space constructions. A new age of civil engineering concerns the creation and exploitation of underground space in the 21st century. Seismic performance standards for the subway's construction are highly stringent since it is one of the city's most common modes of transportation for commuters. Every year, more underground structures increase as the need for transport networks increases. The excavation process requires proper mechanisms to protect the walls adjacent to existing systems and buildings when a structure's subterranean portion spans the entire area [1]. The influence of new underground construction on nearby buildings and other structures is one of the most challenging aspects of this development. Because of their sensitivity to excavation-induced ground movements, these structures' behavior requires artificial intelligence modeling as one of the geotechnical limit states throughout the design process.*

Keywords: Load-settlement behavior, artificial neural networks, Cohesive soils, Pile Foundations

I. INTRODUCTION

Deep underground constructions pose a substantial danger to nearby buildings and infrastructure when they are built. An underground project's primary geotechnical risk is the potential influence of the project's development on nearby buildings. This process is particularly true for projects involving deep excavations and shallow tunnels in densely populated areas[1]. Building methods, design solutions, and construction activities at the site is influenced by the requirement to guarantee the serviceability of surrounding structures, in certain situations, to a significant degree. Humans have long made use of caves and other subterranean habitats. Whether the above-ground land is used for agricultural production or to protect it from natural disasters doesn't matter. Looking back, it's evident that underground construction provided many required circumstances without artificial infrastructure and amenities. The ability to create a highly efficient atmosphere for buildings [2] might be helpful. "There is a lot of room for growth in the subterranean," he says. A well-known British architect, Sir Norman Foster, As a rule, surface construction is the most prevalent kind of construction and is often undertaken by architects, builders, or their clients. As a result, available quality land space, surface natural resources, such as tree felling, and other variables are degraded [2]. Underground construction has many advantages, including decreased carbon footprint, less land usage, reduced temperature variance, and greater catastrophe tolerance. To deal with issues of urban population density and constrained land area, ecologically friendly design, such as underground architecture, should be implemented [2,3]. Integrating subterranean design with sustainable environmental design demonstrated the efficiency of energy use and its low influence on the surrounding environment.

II. RESEARCH PROBLEM

The main problem that this paper will solve is to analyze how predictive and prescriptive techniques are applied in underground structures. Underground space structures are critical in geotechnical construction design for safety and economy [4]. On the other hand, traditional approaches used in this assessment are cumbersome and expensive. The present work attempts to develop a novel methodology to assess the stability and soil properties by applying sophisticated artificial intelligence techniques. ANN handles complicated issues where the connection between the input and output parameters does not follow a linear pattern [5,6]. The modeling step uses a database containing samples from many construction sites.

III. LITERATURE REVIEW

A. Surveys of Underground structures

Tunnels, in particular, are one-of-a-kind architectural creations. The surrounding geotechnical environment is an integral aspect of the tunnel bearing capacity and construction, making their essential design concerns and structural behavior unique. When designing a tunnel, the geotechnical conditions in which it will be built are considered, as well as how it will interact with the surrounding structures and infrastructure [6]. In tunneling, the surrounding soils and rocks serve as the primary load-bearing elements; one goal is to maintain them stable or prevent them from becoming loose. Construction-stage variations in the stress level may cause these impacts. This challenge means tunneling is best done with a continuous building approach that minimizes fluctuations in stress conditions. Consequently, wherever practical, a 24/7 observational design and construction process is preferred [6]. This is a significant distinction between tunnels and other civil engineering constructions.

Observing geological strata on a large scale and conducting in-depth geological investigations are only possible in underground buildings, whether they are used for a laboratory or a waste disposal plant. After the front face is excavated, the geomechanical behavior of the structures is evaluated in situ. While building a deep disposal facility, scientists will use surface research to corroborate their findings and design experimental niches, drifts, cells, or vaults to test their theories. The investigative program may use any procedure related to excavation or site safety[7]. By gathering uncontaminated groundwater samples, boreholes may be drilled beyond the excavation to locate pressurized water or gas zones.

B. Structure and construction of tunnel linings

A tunnel lining is a continuous subterranean layer that carries the weight of water and soil surrounding the tunnel to maintain structural space and stability. Depending on how thick the lining is, it might be classified as either primary or secondary. The main and secondary lining that makes up the double-layer lining design is often referred to simply as "liner." The mainlining is the exterior layer, while the secondary lining is the interior layer. Prefabricated sections known as segments are often used to construct the main lining and are linked with bolts and other fasteners. Concreting the inside of the primary lining creates the secondary lining. The main lining's functions include bearing the internal load created by different pieces of heavy machinery, supporting the structural loads and hydraulic gradient from the strata, and bearing the shield machine's thrust force. Additionally, the secondary lining's main duty is to enhance and support the primary lining's role, but it should also be used to protect against seepage, corrosion, antivibration, and interior ornamentation. The duties of secondary lining also somewhat vary because of the various design purposes [9].

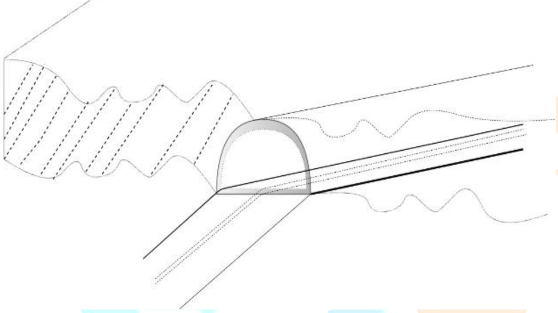

Fig i: Illustration of tunnelling

The principal lining of a shield method tunnel may come in a variety of different shapes. The most popular sort of liner is the one that is constructed. In addition, there are instances of construction using the arched steel columns and back plate supporting technique as well as the in pre - cast concrete coating process (extruded concrete lining). An axial portion (longitudinal direction) of the tunnel's ring, when utilized in conjunction with a constructed lining, is known as a "segment ring"[9]. The n arc-shaped elements make up the segmentation ring's circular division into smaller, segment-shaped units. To expedite the process of constructing the shield tunnel, segments are pieces built in the workshop ahead of time. These segments are composed of reinforced concrete or nodular cast iron. At this time, each section is brought to the building site and put into rings, which are then linked in sequence to form the main lining [10].

C. Predictive and prescriptive analytics methods

The capacity to correctly predict the efficiency speed of mechanical components is one of the primary criteria that supports and facilitates the efficient and successful design of construction activities projects. A construction line for transforming geomaterials into load-bearing foundations is an a good example of why modelling techniques are significant in understanding earthworks and their unique characteristics. Machine learning (ML) algorithms may detect connections between disparate pieces of data even when no previous assumptions have been made. There are a variety of supervised learning ML algorithms available today, each with its own set of pros and disadvantages when it comes to building predicting models based on historical data. Many of these techniques have previously been used to overcome complex geotechnical issues. ANNs and SVMs, two popular supervised modeling AI approaches, are among the many ML algorithms [10]. The human brain's nervous system structure is the inspiration for ANNs, a computational approach. As previously mentioned, nonlinear kernels [11] are a crucial characteristic of SVMs, which implicitly translate the input space to high-dimensional feature space. The support vector machine (SVM) method looks for the linear separation hyperplane that provides the best results for a given collection of support vector points. Despite their differences, both approaches can model a wide variety of data mapping functions, including complicated nonlinear connections. In addition, the findings produced by both machine learning algorithms are often reliable, especially when working with noisy data. They may also be used for both regression and classification problems, which makes them quite versatile. The conventional Multiple Regression (MR) approach was also evaluated in several of the case studies in this work [11,12].

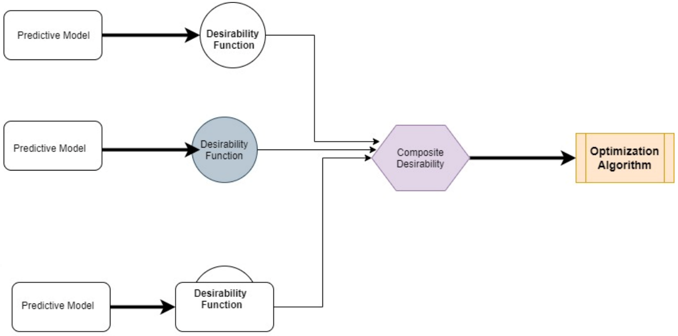

Fig ii: A predictive model process

Metrics for evaluating a model's predictive power will change depending on whether it deals with numeric or categorical data and if regression or classification is required. The MAD, RMSE, and Pearson correlation coefficient (R2) are three often used performance indicators while doing regression assignments [12]. R2 should be close to the unit value, and the first two measurements should show lower values. MAD is less susceptible to extreme values or outliers than RMSE, which is the significant difference between the two measures. Another tool for comparing the accuracy of various regression models' predictions is the Regression Error Characteristic (ROC) curve [12], which depicts error tolerance as a function of the percentage of predicted points falling inside that tolerance on the x-axis. Recall, Precision, and F1-score [12] are three often used performance indicators for classifying jobs. Precision vs. Recall is often a tradeoff. Predictive model accuracy is measured in terms of the model's Recall and Precision, which are based on how many examples of a particular class were correctly predicted by a given model. Using the F1 score, you can see how the Recall and Precision of a course are balanced, resulting in the harmonic mean. The classifier's accuracy may vary from 0% to 100% for these three measures [13].

There are various ways to validate a data-driven model's capacity to generalize. Validation using k-fold cross-validation, which separates the available data into k distinct subsets and results in k training and testing grounds, is a well-known and common practice. There are k iterations, and a new subgroup of the ML model is tested each time, while the rest is utilized for training. Ultimately, all data is used for training or testing purposes. It is essential to highlight that the assessment metrics are always calculated using test data that has not been seen before (as provided by the cross-validation procedure).

Predicting future values of crucial geotechnics variables is simple using an accurate generalization machine learning (ML) model[13]. Infrastructure management indicators such as expected construction time and maintenance costs may be estimated using these forecasts and known values (e.g., gathered in a database). A search area may be defined for EC to utilize to optimize or minimize various objectives depending on the different management choices (e.g., setting maintenance budgets) (e.g., increasing the quality of construction roads, reducing costs, and minimizing environmental impact). To help in geotechnical planning, predictive machine learning (ML) models can be used in conjunction with expert judgment.

D. Case Study: China

Civil air defense in China sparked the creation and use of underground space in China. Since China's rapid economic growth began in the late 1990s, the subway construction industry has grown exponentially, with the city subway station serving as the focal point for the development of underground shopping malls, underground commercial streets, and other urban underground complexes. Chinese urban subterranean space growth and usage have entered a short development period [14] as the country moves into the golden era of subway construction [15]. The building of a subway system in Wuhan is on the rise, but it will also help spur the city's underground area to expand quickly, which has enormous development potential. Lifeline engineering, which includes underground structures like subway stations, is an excellent area for earthquake avoidance and evacuation [15]. As a result of the city's seismic issue, earthquake engineering, catastrophe prevention, and urban engineering have become more prominent fields of study. Due to a lack of interest in earthquake-induced destruction of early subterranean structures, people formed the erroneous notion of underground excavation in the earthquake. They ignored the underground system of earthquake design due to these factors. However, the 1995 Hanshin earthquake badly damaged the Kobe City subway station and the tube that connects it to the rest of the subway system, drawing numerous earthquake workers' attention. The earthquake in Japan's Hanshin region reveals that the underground structures, such as the subway and other layers, may have been severely damaged[15]. Before the 1995 Hanshin Earthquake in Japan, earthquakes and minor water supply systems were reported to have been damaged by previous earthquakes.

Eruptions such as this were very infrequent and caused minor damage. While the freshly constructed Tianjin subway has been tested by an earthquake (with a magnitude of 7 to 8 degrees in Tianjin), only the sinking site's surface layer has shown evidence of local shedding or fractures, like in the 1976 Tangshan earthquake (ML7.8). As an additional illustration, consider the earthquake of 1985 (ML8.1), which shattered sections of the box-shaped subway tunnel's soft foundation as it transitioned from its basement to its top portion of the transition zone. Tunnel advancement causes longitudinal fractures and dislocation of concrete in the tunnel pipe junction due to the cutting of bolts connecting that section to the working shaft. The opposite end of the tunnel also experiences longitudinal cracks and dislocation. The damage to the excavation tunnels in Kobe is severe, but the damage to the shield tunnels is minimal. Approximately ninety percent of the 900-meter interval tunnel between the old and the new stations has a break on the left or right side of the wall, and water is leaking[15]. On the other hand, the shield tunnel was quickly placed into service after the earthquake, showing that it has suffered less mild damage than the subway station.

E. Seismic Analysis: A Real-World Case Study

Before the 1950s, a Japanese professor named Dasen Sumer developed the first technique of seismic analysis. This approach was created in Japan. Depending on the force applied compounded by an empirical coefficient, the engineering technique was simple to use and well regarded in the early 1960s by the former Soviet academic Fodieva, who evaluated the structures in each of the different permutations of pressure-pull waves and shear waves in every direction of the transverse section of the design. Under the operation of the subsurface security system, the suggested general solution may be in its most adverse condition possible based on the earthquake. In the same era, Newmark and colleagues came up with a free-field deformation technique, which is a technique that directly applies the displacement that occurs in a variety of free-field structures when they are subjected to seismic activity. BART's 1969 subway design standards and the SCETD design principles, adopted for the Los Angeles Mass Transit Railway in 1990, were governed by this legislation. Japanese researchers began their investigation into the geotechnical deformation of the area in the late 1970s using seismic monitoring data, making it evident that subsurface structure—rather than inertia—plays a crucial role. According to [16] field observation and model testing, a mathematical model is created. As a result, a response displacement approach for seismic response analysis of subterranean structural cross-sections is provided. Using the notion of elastic foundation beams, an American researcher in the 1980s argued that the tunnel-ground soil interaction issue is analogous to the quasi-static problem. When Dasgupta came up with the idea of dynamic impedance matrixes in the cross-section simultaneously, it was revolutionary.

IV. SIGNIFICANCE TO THE U.S

The US construction sector relies heavily on predictive and prescriptive analytics, particularly for underground projects like tunnels. Any country's transportation infrastructure is of the utmost significance. This infrastructure's development, administration, and upkeep is a labor-intensive process that necessitates several resources (such as labor, materials, and maintenance expenditures) [17]. In the tunneling sector, new ideas are generated by the rivalry between specialized contractors and the technical difficulties faced during tunneling construction activities. Normal development may play an essential role in enhancing scientific collaboration between nations and persons participating in these efforts [17]. It is crucial to have a robust site characterization based on developing a predictive ground model to control the hazards necessary for many projects that lurk under the surface. Pre-construction geophysical screening is are compared to breakthroughs in medical diagnostics made possible by scanning technology. Predictive ground models provide for the avoidance of undesirable events, including inefficient design, squandered resources, and overrun timelines.

V. FUTURE IN THE UNITED STATES

The use of predictive and prescriptive analytics will become more critical in developing underground space structures in the United States. In light of the rising number of existing tunnels, maintaining the structural integrity of older tunnels will become more critical. Existing tunnels are getting more attention than new ones when allocating funds for infrastructure improvements. This tendency will only become more robust with the increasing number of tunnels and underground systems. As cities grow and expand, greenfield developments will become more of an exception rather than the norm, and the need for accessible subterranean space will rise throughout Europe [18]. Parallel to this, the necessity to correctly analyze and mitigate the consequences of tunneling below and above ground necessitates the thorough assessment and mitigation of tunneling's impact on existing structures. Even if current standards don't cover new building methods and materials, clients, designers, and contractors will be challenged to use them in future projects—even if they aren't covered by current standards [18]. Tunnel design and construction are hindered not only by technical challenges that a new normal may be able to alleviate to some degree but also by contractual concerns. Two of the most promising areas for future growth in the tunneling industry

VI. CONCLUSION

This study presented an overview of how predictive and prescriptive analytics is used to subsurface space constructions. In addition, research has revealed that for a. There are several uses for underground infrastructures, including subways, trains, and highways, as well as material storage and sewage and water transportation. In earthquake-prone regions, it is necessary to design and construct underground infrastructure that can bear seismic and static loads. Historically, damage to subsurface infrastructure has been less frequent than damage to buildings on the surface. Data analytics and real-time application are critical in the Big-data age because of the massive amounts of data being generated rapidly. Future trends may be predicted and prescribed using predictive and prescriptive analytics. This will assist in determining the data's usefulness and, as a result, its long-term retention for use in other applications. The formwork is crucial in civil engineering since it serves as a template for fresh concrete castings. Concrete engineering time and cost are directly impacted by the template's quality of production and installation and the simplicity with which it may be taken apart and reassembled and reinstalled on subsequent projects. Appropriate template form, structure, and building technique must be selected based on the project's structural and construction parameters to guarantee the quality and safety of the concrete construction.

REFERENCES

[1] D. Perugini and M. Perugini, "Characterised and personalised predictive-prescriptive analytics using agent-based simulation," *International Journal of Data Analysis Techniques and Strategies*, vol. 6, no. 3, p. 209, 2014. Available: https://doi.org/10.1504/ijdats.2014.063059

[2] G. C. Deka, "Big Data Predictive and Prescriptive Analytics," in *Advances in Data Mining and Database Management*. IGI Global, 2014, pp. 370–391. Available: https://doi.org/10.4018/978-1-4666-5864-6.ch015

[3] I. C. o. M. Lear, Proceedings of 2004 International Conference on Machine Learning and Cybernetics: August 26-29, 2004, Worldfield Convention Hotel, Shanghai, China, V. Institute of Electrical & Electronics Enginee, 2004.

[4] I. C. o. M. L. (. 2. W. College), Machine learning: Proceedings of the eighteenth International Conference (ICML 2001) : Williams College, June 28-July 1, 2001. San Francisco, Calif: Morgan Kaufmann Publishers, 2001.

[5] H. Zhang, "Multi-objective simulation-optimization for earthmoving operations," *Automation in Construction*, vol. 18, no. 1, pp. 79–86, Dec. 2008. Available: https://doi.org/10.1016/j.autcon.2008.05.002

[6] F. Cheng, Y. Wang, and X. Ling, "Multi-Objective Dynamic Simulation-Optimization for Equipment Allocation of Earthmoving Operations," in *Construction Research Congress 2010*, Banff, Alberta, Canada. Reston, VA: American Society of Civil Engineers, 2010. Available: https://doi.org/10.1061/41109(373)33

[7] A. T. Tolmidis and L. Petrou, "Multi-objective optimization for dynamic task allocation in a multi-robot system," *Engineering Applications of Artificial Intelligence*, vol. 26, no. 5-6, pp. 1458–1468, May. 2013. Available: https://doi.org/10.1016/j.engappai.2013.03.001

[8] T.-m. Cheng, C.-w. Feng, and Y.-l. Chen, "A hybrid mechanism for optimizing construction simulation models," *Automation in Construction*, vol. 14, no. 1, pp. 85–98, Jan. 2005. Available: https://doi.org/10.1016/j.autcon.2004.07.014

[9] H. S. H. Alzraiee, "Hybrid Simulation for Construction Operations," Thesis, 2013. Available: http://spectrum.library.concordia.ca/977560/1/Alzraiee_PhD_F2013.pdf

[10] R. A. Smoak and X. R. Ollat, "Construction of control design models from engineering simulation models," *Mathematical and Computer Modelling*, vol. 14, pp. 413–417, 1990. Available: https://doi.org/10.1016/0895-7177(90)90218-c

[11] K. U. Hellmold, "The Modular Construction of Models," in *First European Simulation Congress ESC 83*. Berlin, Heidelberg: Springer Berlin Heidelberg, 1983, pp. 53–57. Available: https://doi.org/10.1007/978-3-642-69295-6_5

[12] P. Cortez and M. J. Embrechts, "Using sensitivity analysis and visualization techniques to open black box data mining models," *Information Sciences*, vol. 225, pp. 1–17, Mar. 2013. Available: https://doi.org/10.1016/j.ins.2012.10.039

[13] P. Cortez and M. J. Embrechts, "Opening black box Data Mining models using Sensitivity Analysis," in *2011 Ieee Symposium On Computational Intelligence And Data Mining - Part Of 17273 - 2011 Ssci*, Paris, France, Apr. 11–15, 2011. IEEE, 2011. Available: https://doi.org/10.1109/cidm.2011.5949423

[14] S. Coulter and C. D. Martin, "Single fluid jet-grout strength and deformation properties," *Tunnelling and Underground Space Technology*, vol. 21, no. 6, pp. 690–695, Nov. 2006. Available: https://doi.org/10.1016/j.tust.2005.12.136

[15] A. P. Frolov, "Group properties of the equations of a single jet stream of an ideal fluid," *Journal of Applied Mechanics and Technical Physics*, vol. 8, no. 3, pp. 77–78, 1971. Available: https://doi.org/10.1007/bf00913219

[16] M. Yoshida, T. Sumomogi, T. Kino, M. Okumiya, and Y. Tsunekawa, "The Relation of Crystallographic Plane with Strength and Deformation Properties of High Purity Aluminum Single Crystals during Nanoindentation," *Journal of the Japan Institute of Metals*, vol. 73, no. 2, pp. 95–102, 2009. Available: https://doi.org/10.2320/jinstmet.73.95

[17] D. J. Edwards and I. J. Griffiths, "Artificial intelligence approach to calculation of hydraulic excavator cycle time and output," *Mining Technology*, vol. 109, no. 1, pp. 23–29, Apr. 2000. Available: https://doi.org/10.1179/mnt.2000.109.1.23

[18] A. Göktepe, A. Lav, S. Altun, and G. Altıntaş, "Fuzzy Decision Support System to Determine Swell/Shrink Factor Affecting Earthwork Optimization of Highways," *Mathematical and Computational Applications*, vol. 13, no. 1, pp. 61–70, Apr. 2008. Available: https://doi.org/10.3390/mca13010061

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