"Comparative Study of 2-Dimensional and 3-Dimensional Analysis of a Deep Excavation in Situ Measurements"

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Abstract
The process of designing for deep excavations is a difficult one that requires taking into account a broad variety of aspects. These factors include the processes that are involved in developing the excavation as well as the physical characteristics of the soil. The use of finite element analysis can be beneficial to the design of deep excavations; however, it must be carried out with caution in order to guarantee that an acceptable quantity of information is included in the model. A diaphragm wall, a jet grout panel, and three layers of struts were used to provide support for the excavation. When the lower rigidity of the diaphragm wall owing to cracking was taken into consideration, evaluation and comparison with in-situ measurements indicated that the best agreement with the data occurred.

Key Words: Soil, Finite Element Analysis, Mesh, Struts, Grout panel

1. Introduction

There are now a lot of subterranean hydroelectric projects being developed to harness the power of river currents. Digging underground causes significant changes to the stresses on the surrounding rock. In order to determine the stability of such openings, it is necessary to conduct a thorough study of the stresses and deformations in the rock mass, rather than relying on approximate or average estimates. However, it is expected that modeling would be constrained by the difficulties of getting precise input data. Thus, numerical simulation has recently superseded the more conventional modeling, where the properties of the rock mass are established either by empirical techniques based on hundreds of case histories or by rational ways based on largely laboratory or in situ testing.

The design of a reliable support system is dependent on a precise evaluation of the stresses in the rock mass around any underground boreholes. The discontinuities, nonhomogeneities, and in situ stress states must all be taken into consideration during this assessment of the rock's (many) material properties. It is also important to consider the nonlinear constitutive behavior of the rock since significant strain deformations are possible. When faced with such challenges, finite element analysis has shown to be a useful technique. According to a comprehensive review of the current literature on the issue, the rock mass characteristics that are presumed or typical of the rock mass are employed in stability evaluations of underground apertures. Nonsymmetric apertures in 3D finite elements need more information than is currently available in the literature. Therefore, in order to effectively design underground apertures, it is crucial to use an analytical model that is appropriate for the materials involved and the context of the design.

The construction of basements and other subterranean infrastructure, such as transit and road tunnels, is expanding at an unprecedented rate as cities seek to maximise the use of their limited land resources. There is room for improvement in the existing practise towards comprehensive urban sustainability through strategic decision-making during design and construction that takes into account the subterranean for future usage. As a solution to the problems caused by their rapid expansion, contemporary cities often use pile foundations to sustain clusters of tall structures. Existing structures' pile foundations may be considerably impacted by the deep excavation required for the planned new construction if, as is usually the case, little consideration was given to how the area beneath or surrounding them may be utilised in the future. Massive economic losses, numerous casualties, and far-reaching societal consequences will follow. A 13-story pile-supported skyscraper in Shanghai, China's Minhang District collapsed in a devastating disaster. The piles were unstable as a result of the weight of the excavated material and the soil softening from the subsequent rain event, which had far-reaching societal consequences. For a long time, researchers have been trying to figure out how to fix this sort of problem, but after years of effort and several large-scale studies, they have yet to succeed.
One numerical technique for solving partial differential and integral equations with reasonable precision is the finite element method (FEM). The differential equation may be eliminated entirely (steady-state problems), or the PDE can be transformed into an approximation system of ordinary differential equations that can be numerically integrated using well-established techniques like Euler's method. This project is using the FEA-based geotechnical application PLAXIS 2D to do an elasto-plastic analysis.
For geotechnical engineering and rock mechanics applications requiring two-dimensional analysis of deformation and stability, PLAXIS 2D is a robust, user-friendly finite element programme. It is widely used in the fields of civil and geotechnical engineering, and is the standard tool of many of the world's leading engineering firms and academic institutions. Excavation, embankment, and foundation work, as well as tunneling, mining, and reservoir geo-mechanics, are just a few examples of possible applications. Using PLAXIS, you may simulate a wide variety of geotechnical issues without having to switch between different programs.
In a CAD-like environment, PLAXIS makes use of preset structural parts and loading types. With the time saved from the streamlined model building process, the user is free to focus on making sense of the outcomes. With an intuitive interface, users are led through a systematic geotechnical process that results in an efficiently crafted model. The flexible output programme allows for the presentation of force, displacement, stress, and flow information in a number of different formats, including contour, vector, and data transferred from tables or python based scripting for processing beyond PLAXIS. The curve manager allows users to make graphs by plotting different kinds of outcomes from calculated data.

Review Of Literature

Houhou, Mohamed Nabil, et al., (2019) Modern city design often makes use of underground spaces, and each year sees an increase in the number of enormous excavation trenches in the center of cities. Estimating not just the lateral displacement of retaining walls but also the

movement of the retained soil is becoming increasingly crucial in order to limit the impact that excavations have on neighboring buildings. Empirical approaches that are based on experimental data have been established in order to characterize the displacements field brought on by excavation in the greenfield hypothesis. These methods were developed. When analyzing more complicated situations, however, the use of numerical tools could be beneficial. In this study, we take a closer look at a single case in which a deep dig was being watched over in close proximity to an already existing building. Due to the fact that it was constructed inside an over consolidated molassic geological context, the Saint-Agne station on the new line B in Toulouse, France, features a diaphragm wall that is supported by up to three layers of steel struts. A compilation of data obtained from various monitoring tools has been contrasted with the results of a 3D numerical analysis carried out with the help of a finite difference algorithm. This algorithm takes into consideration the dewatering process by performing an uncoupled flow-mechanical calculation. The numerical findings and the monitoring data are very congruent with one another. There is a high degree of consistency. Additionally, the model provides specifics on the 3D behavior of the excavation and how it will have an impact on the neighboring structures. While attempting to predict excavation behavior, some brief remarks are made on the disparities that have been found between the results of 2D and 3D numerical analysis.
Khac-Hai Phan, et al (2019) It is intended to investigate the behaviours and mechanisms of a deep excavation in sand that result from a single strut failing, as this is recognised as a major contributor to the overall failure of the deep excavation and has been incorporated as a design requirement in some countries around the world (OSF). To perform the aforementioned evaluations, we use finite element analyses with three-dimensional modelling to simulate scenarios in which a single strut is removed from a variety of locations and depths throughout various phases of excavation. The behaviours and mechanisms under these conditions are investigated and described, with particular focus on the variation of effective horizontal stresses of soil mass and strut loads. Although this study only covers the OSF example in sandy soil, comparable weight transmission mechanisms and effect zone consequences following the occurrence of a single failed strut are seen in excavations in clayey soil, suggesting that more research and debate are warranted.
Amir Zad & Mehrdad Farnegin (2017) Massive subterranean caverns were planned and built to meet the need for parking in Iran's rapidly expanding cities. Nailing earth into place as a temporary support for deep excavations is a common practice in Tehran. In order to simulate and anticipate lateral motions and settlement, it is common practice in excavation design to use a planar strain condition using a two-dimensional finite element approach. The distribution of horizontal earth pressure is significantly influenced by corners, which in turn significantly influences lateral movement, according to reviews of pertinent literature and observational data. This finding suggests that three-dimensional numerical modeling is necessary for more accurate movement prediction. Parametric modeling of a 15-meter-deep excavation with a soil-nailing system of support in PLAXIS 3D A.E. 2015 is shown here. You may change the size of the nails, how far apart they are spaced, and even the sort of constitutive soil model used. The findings, which account for the three-dimensional effects of corners, indicate that the soil nail distance at concave corners should be increased. This might

result in a better functional layout for the soil nailing technique.

Georgiannou, Vasiliki, et al (2017) The use of prefabricated pieces to support subsurface cylinder holes is investigated in this virtual research. A vertical cylinder shaft may be dug and borne in low-cohesion, dry soil using a method called underpin. This investigation's major concentration will be on the stress distribution along the shaft under various three-dimensional loading conditions. In the beginning, the excavation was modeled as an axisymmetric issue using the "PLAXIS 2D" finite element tool. Following that, the aforementioned technique of analysis is validated using the complementary "PLAXIS 3D" finite element analysis. In the course of this research, several attempts have been made to zero in on the aspects that prove to be the most significant. The constitutive model, also known as the "Mohr-Coulomb" or "Hardening-Soil" model, is what is more significant when attempting to describe the behavior of the soil than the diameter of the shaft. According to the findings of the study, the shear strength parameters (c', ') at the soil-structure interface and the value of "Unloading-Reloading Modulus" (Eur) have been found to have only a little influence on the results. The calculations bring to light a number of problems, the most notable of which are the high values of tangential hoop stresses seen in the circular segmental rings, the floor uplift that occurs as a result of unloading, and the creation of an excessive plastic zone around the bottom of the vertical shaft. All of these problems were discovered as a result of the calculations.

J.C.S. Tito & C. Romanel (2014) Problems of instability in deep excavations are a current difficulty because of the requirement for large-scale engineering undertakings. Service well PS - 39 was dug as part of the executive project of collectors for the treatment of sanitary sewage in Rio de Janeiro, and its excavation is the subject of this article's inquiry and verification. A wall of secant columns, a shotcrete ring structure atop the columns, and a slab of jet grouting kept in place by passive tiebacks made up the construction system utilized to construct the well. Based on available geotechnical information from field instruments, laboratory data, and a targeted literature research, the soil characteristics of the various strata that make up the geotechnical profile were calculated in preparation for numerical modelling using the Mohr-Coulomb constitutive model. Using PLAXIS 3D (2012), we were able to calculate the stresses and displacements that occurred throughout the excavation process, as well as our interpretation of those data. Instrumental measurements were used to verify these findings; next, the numerical model will provide reasonable predictions about how the predetermined soil-structure will behave during excavation. As a result, we can anticipate and prepare for issues of a similar nature.

Law, Kim Hing, et al (2014) Through the use of 2D and 3D finite element (FE) simulations, as well as two case histories from Kuala Lumpur, Malaysia, this study investigated the features of the stiffness of the Kenny Hill formation residual soils. In this work, we made use of the Hardening Soil (HS) model that is a part of the PLAXIS finite element software, which is quite popular. By contrasting the outcomes of 3D FE back-analyses with the horizontal wall deflections that were actually recorded, we are able to understand how the soil stiffness parameters of the HS model influence the movement of the walls. Analyses of the parameters revealed that the HS model was capable of reliably predicting horizontal wall deflections at each level of excavation. This was accomplished by establishing a clear relationship between stiffness parameters and N values derived from field standard penetration tests (SPT). The HS model calculated that a triaxial secant's Young's modulus is about similar to 1500N kPa at a reference pressure of 100 kPa. The provided case studies illustrate the relevance of setting the soil modulus parameters and also taking into account the geometrical or corner influence when evaluating excavation performance.

I. Material Parameters

Project description

The excavation has a roughly square shape in plan, measuring around 19 m by 20 m, which naturally raises questions about the applicability of a 2D study. It is important to note that a jet grout panel was built to provide lateral support immediately below the final excavation level. This was built ahead of time so that work could begin in the excavation without having to set up a fourth structural level. To mitigate uplift, vacuum wells were drilled below the excavation level to drain groundwater from within the excavation.

The breakdown depicts the sequence of construction. During the on-site construction of the wall and jet grout panel, it was important to take into account the initial stress condition (K0 = 0.55 for all layers) as well as loads coming from neighboring building foundations (80 kN/m2 for the Novotel and 200 and 250 kN/m2 for the strip footings of Object 24). Then, the process of excavation, groundwater fluctuations, and strut installation were modeled and analyzed in detail. Due to the presence of thin sandy layers, we may anticipate untrained soil behavior below 20 meters and drained soil behavior above 20 meters.

Material parameters

The study took into account the properties of both the topsoil (the upper few meters of the soil) and the clayey silt layer below. Parameter evaluation, as was previously said, relies not only on in-person observations and lab testing, but also on what was learned through extensive digging in the past. We did not make any attempts to change the thermal properties of the soil throughout this study.

Between the first and third levels, the struts' axial stiffness varies, and the projected material behavior is linear elastic. Uniaxial compressive strength (UCS) was determined in 2D investigations of the wall and jet grout panel using the Mohr-Coulomb failure criteria, assuming ′ = 45o. The level of stress was calculated to be 10 UCS units. "rinter" refers to the process of artificially reducing soil strength to increase wall friction. In the 3D models, an elastic wall was employed, and the states of "uncracked" and "cracked" were represented by different stiffness values. Because it is extremely challenging to accurately measure the in-situ stiffness of panels of this kind, the stiffness specifications of the jet grout panel have been adjusted.

II. In Situ Measurement Programme

It was crucial to keep a close eye on the ground level because of the neighboring structures. In order to monitor the structural integrity of the structures located in the excavation zone, about thirty settlement gauges were installed. During the building process, four inclinometers were mounted on the inside of the diaphragm walls in order to measure the horizontal deflection of the walls. Two were located about in the cross section that was selected for the 2-Dimensional investigation. This cross section matched to the longitudinal axis of the excavation. The places that were selected for the settlement measurement and analysis are shown in Figure 1.

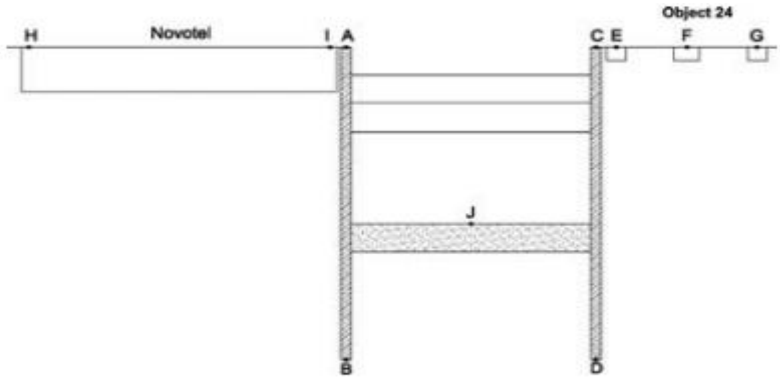

Figure 1: Points Location used for comparison

III. Numerical Models

Plaxis 2D and Plaxis 3D Foundations have been used for both 2D and 3D analysis, as shown by their existence. The 2D model in Figure 2 is composed of roughly 2,300 15-noded components, whereas the 3D model in Figure 3 is composed of about 11,000 15-noded wedge parts. Both versions have horizontal sides and vertical bottoms. The sides are also fixed in a horizontal plane. However, bending moments are more susceptible to discretization, therefore a stability study is unlikely to provide reliable results when utilizing the mesh used for 3D investigations.

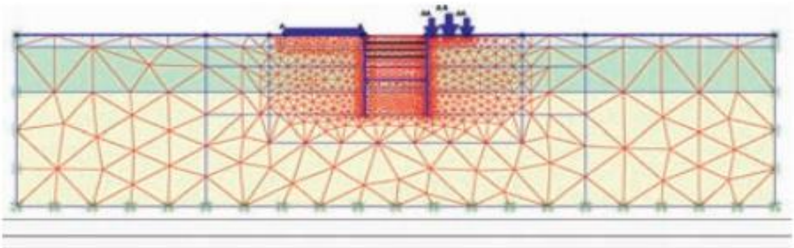

Figure 2: 2-Dimesional finite element mesh

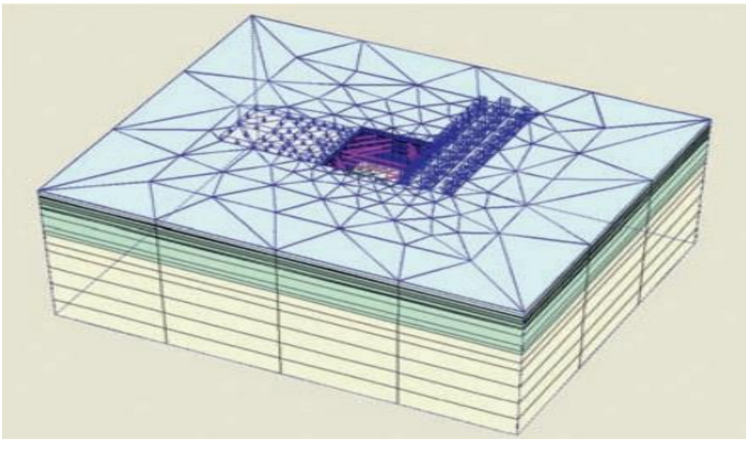

Figure 3: 3-Dimensional finite element mesh

IV. Comparisons Of Results Of 2d And 3d Model

The assumption of "cracked stiffness" yields a better fit to the measured curvature than the analysis with high wall rigidity, at least for the right wall, when comparing horizontal displacements caused by altering the stiffness of the diaphragm wall in the unsupported zone. Because the top part's behavior is mostly determined by the struts, less horizontal displacements than those seen are to be anticipated. The non-linear model, as may be expected, finds a happy medium between these two options.

Finally, an additional study was performed after discussing the issue with the designer and assuming a less-than-ideal connection between the struts and the wall. Because of this, it was assumed that more effort would be necessary to completely activate the strut's support. Because the nonlinear strut model has a variance of 0.25 mm/m before complete support is provided (denoted as V7 in the accompanying figures), this "gap" must be crossed. The results of the 2D analysis (for the fourth variant) are shown in Figures 4 and 5. The top of the left wall now conforms much more closely to specifications than it did before, although the curve where the grout panel will go is still off a little. The right wall's top part and curvature now accord in size (the 2D study for the right wall also shows strong agreement).

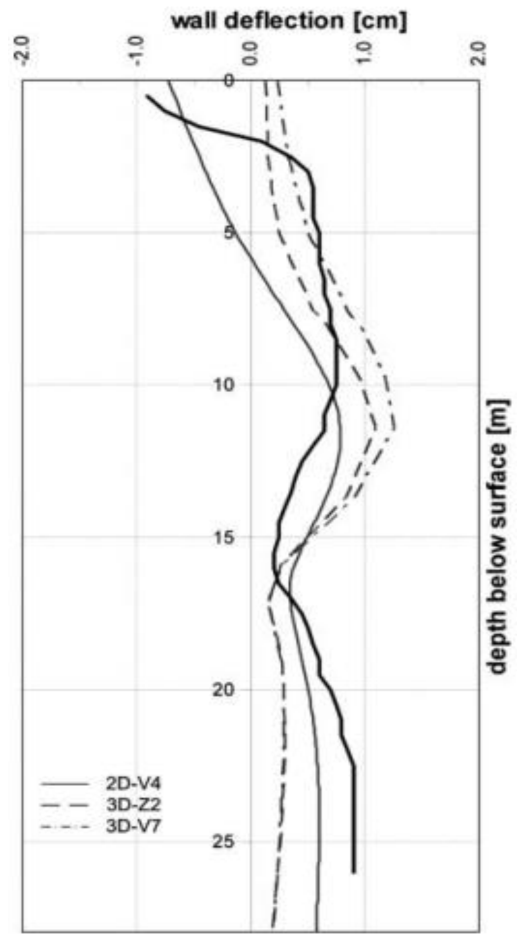

Figure 4: Comparison of left wall

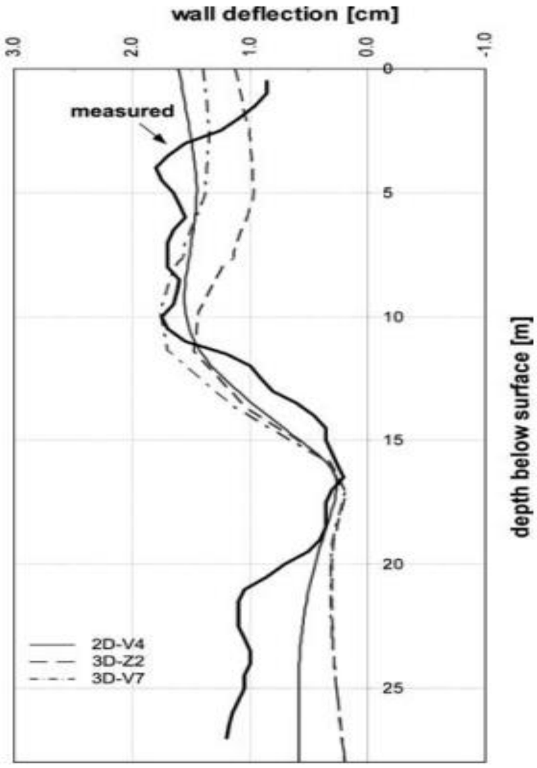

Figure 5: Comparison of right wall

In Figures 6–9, we see the progression of settlements from different vantage points. It is instantly apparent that the 3D analysis predicts settlements also for Point I, but at slightly lower levels than those actually recorded. Settlements measured and calculated are very close to zero; hence point H is a good match. For later phases of building, as shown by point E, settlements are slightly higher than measured, and this is also true for point G.

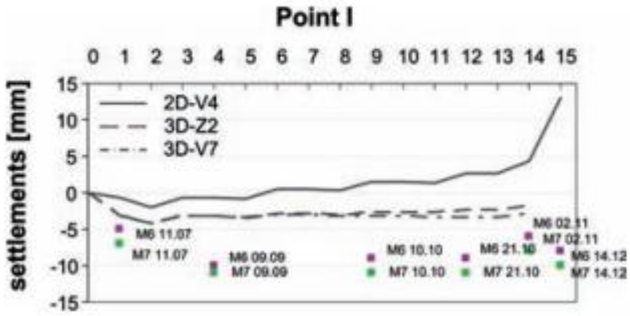

Figure 6: Comparison of Point I

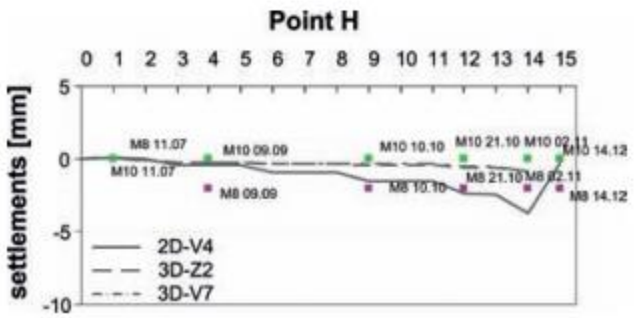

Figure 7: Comparison of Point H

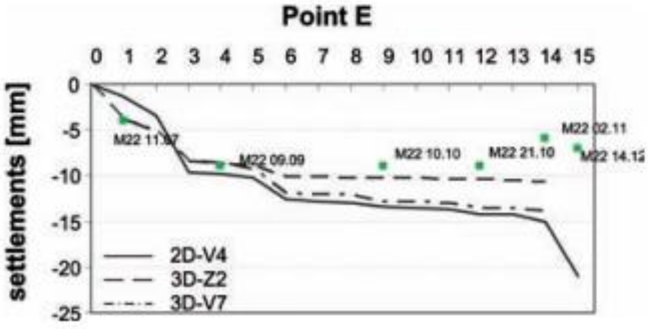

Figure 8: Comparison of Point E

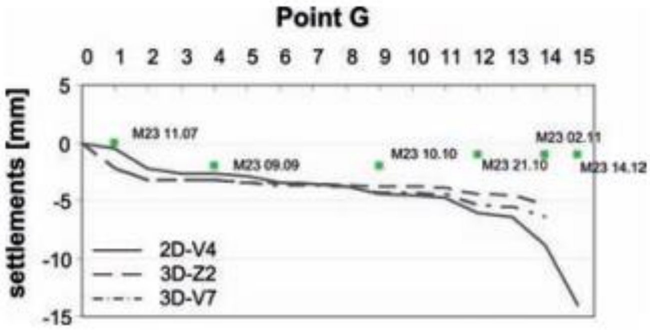

Figure 9: Comparison of Point G

V. Conclusion

Two-dimensional and three-dimensional finite element calculations have been compared to information gleaned through extensive digging. Along with a diaphragm wall and three rows of struts, an excavation is supported by a jet grout panel set at or just below the ultimate excavation depth. The findings indicated that while wall deflections could be reasonably predicted using a 2D analysis (particularly for the right wall), a 3D analysis, which included both walls and the vertical displacements of all surface locations, produced a somewhat greater overall agreement with the measurements. Three-dimensional finite element analysis may provide precise data on the progress of a complex deep excavation. However, the model's effectiveness and the desired results depend on a number of factors that must be carefully evaluated.

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