Bentley
Advancing Infrastructure


Image courtesy of SOM and GuocoLand

Project Summary

Organization:
Arup Singapore Pte. Ltd.

Solution:
Geotechnical Engineering

Location:
Tanjong Pagar, Singapore

Project Objectives:

- To undertake geotechnical engineering for a development that includes Signapore's tallest tower.
- To minimize the impact of underground work on existing structures.
- To advance the observational method in building construction and demonstrate sophisticated modeling coupled with real-time monitoring for advanced analysis.

Project Playbook:
gINT®, MicroStation®, PLAXIS®

Fast Facts

- Arup Singapore used gINT to manage all geotechnical data throughout its work and examine the complex sediment to produce a full geotechnical interpretive report.
- By incorporating data from gINT and ground sensors into PLAXIS, the team created soil simulations and refined the design.
- The project team decided on a pile-raft foundation, and used 3D modeling to predict the performance of individual piles.

ROI

- Geotechnical studies within gINT kept soil movement on nearby structures below government limits.
- PLAXIS allowed the company to streamline support structures and reduce the load on bored piles by 30% to 35%.
- Using PLAXIS as an all-in-one soil and structure response solution saved time and prevented the need for additional software.

Arup Singapore Utilizes 3D Soil Simulations to Design the Foundation of the Tallest Tower in the Country

The Project Team Saved Resource Hours and Avoided Using Multiple Software Platforms with Bentley Applications

Variable Soil Presents Foundation Challenges

Arup Singapore Pte. Ltd. is the local branch of Arup Group Ltd., a London-based firm that provides engineering, architecture, design, planning, project management, and consulting services around the world, having completed projects in 143 countries. GuocoLand (Singapore) Pte. Ltd. contracted Arup Singapore to provide civil and structural services for a development that would include the tallest tower built in the country.

The SGD 3.2 billion Guoco Tower, formerly known as Tanjong Pagar Mixed Development, includes a 64-story, 290-meter office and residential tower, a medium-rise hotel block, a six-story podium for commercial use, and a three-story basement with a direct link to an existing Mass Rapid Transit (MRT) station. Though large and complex, the development was slated for the center of Singapore's bustling central business district.

Early on, developers realized that the soil in the area would present a significant challenge. The area includes dolomite, limestone, mudstone, sandstone, and shale that is highly permeable and can vary greatly in composition. Excavating the huge amount of dirt necessary for the basements and foundation posed the risk of soil deformation in the surrounding area.

Due in part to increasing amounts of underground development in already-congested spaces, the Singapore local authorities mandated that the movement of MRT structures—which needed to continue functioning throughout construction—be limited to a maximum of 15 millimeters in any direction. Furthermore, movement of a row of shop houses, which was only 20 meters away from the site, was limited to a maximum of 25 millimeters. "These shops are 100 years old and are recognized as a cultural feature of Singapore," said Ei Sandar Aung Win, senior geotechnical engineer with Arup Singapore.

Digging Deep with gINT

Arup Singapore determined that the project would require a detailed analysis of sub-soil conditions performed using robust geotechnical solutions, which would provide the team with a solid foundation to address the effects of excavation on the older structures. However, the team had to do all of this while facing a tight deadline. To overcome the challenge, Arup Singapore deployed Bentley's gINT geotechnical and geoenvironmental software to manage the data throughout its work. Using gINT, the project team examined the complex sediment and gave geotechnical engineers a better understanding of the soil properties of any given area of the development. This capability also allowed engineers to accurately determine what special tests were needed for each section, as well as helped team leaders easily communicate their findings to project stakeholders. In just one week after completing ground-investigation works, the team was able to produce a full geotechnical interpretive report that assessed all soil properties and ground risks.

The gINT study revealed that the ground was in reasonably good condition. However, the analysis also showed that the 290-meter tower would require a deep foundation to avoid disrupting the raft foundation of the nearby MRT station. Ideally, the foundation would minimize ground disturbances but remain flexible enough to allow for the tower's construction. Arup Singapore chose a design that combined a raft and numerous piles penetrating the ground. "Piles can be further optimized by working together with the raft while maintaining the tower's settlement within an acceptable range," Ei said.

During the construction phase, the contractor proposed a sequential excavation process that divided the area into sub-zones—two for the MRT station, and one each for the tower and hotel—that would properly control the retaining wall deflections and speed construction. However, this situation would cause a significant impact on initial design prediction of soil movements.

Accurately Predicting Soil Behavior to Streamline Design

Arup Singapore incorporated data from gINT and actual field monitoring records into PLAXIS to create soil simulations and refine the initial design, which helped the project team predict more accurately soil stresses and ground movements using input from the PLAXIS 2D SoilTest capability.

"Bentley's geotechnical software enhanced the design methodology and drove efficiencies through digital workflows, which helped us to deliver a safe and cost-effective solution for basement construction, as well as resolve site issues and challenges encountered during construction."

– Ei Sandar Aung Win, Senior Geotechnical Engineer, Arup Singapore

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PLAXIS 3D allowed the project team to capture the complex interaction between the proposed pile-raft foundation, phased excavations, and the existing structures more effectively. Arup Singapore complemented the overall foundation model with independent 3D models that would calibrate via on-site load test data and simulate the performance of individual piles. Moreover, PLAXIS 3D's iteration capability enabled Arup Singapore to predict how the tower would settle over time by calculating more accurate soil values and providing realistic raft behavior.

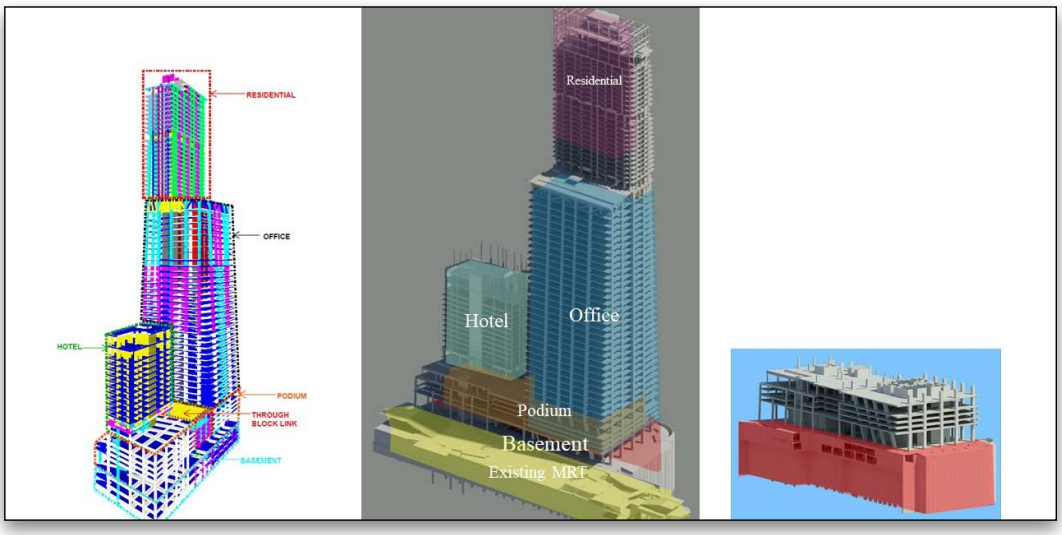
By using PLAXIS as an all-in-one soil and structure response solution, Arup Singapore saved resource hours and eliminated the need to use numerous software platforms. The organization also used the software to prove that the impact of the excavation and the influence zone would be smaller than what regular analysis could predict. These results made the submission process faster and eliminated the need for impact assessment and strengthening works.

Working within PLAXIS also helped the project team streamline excavation and foundation design. After work began, the contractor asked that Arup Singapore omit an expected soil berm and some inclined corner struts due to site constraints. To meet this request, the project team analyzed field performance and compared it with the model in PLAXIS, determining that the design could work without those features, and other strengthening measures were not needed.

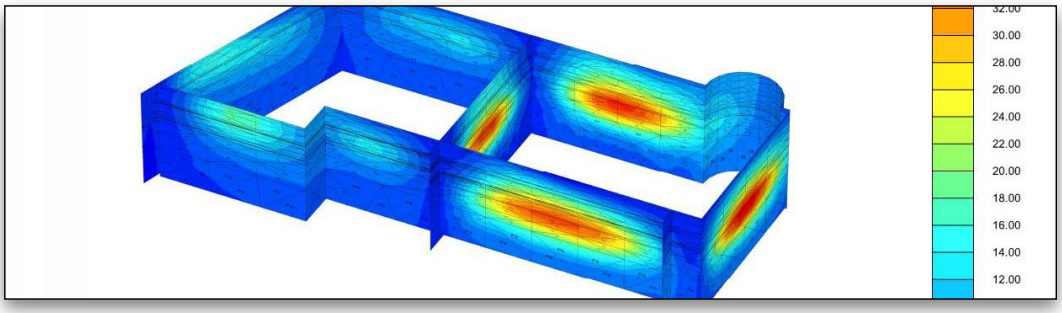
Incorporated Sensors to Keep Soil Movement Well below Regulated Limits

Arup Singapore continued measuring soil performance during and after construction with special instruments like flat cells, piezometers, and strain gauges installed underneath the raft. These instruments proved that, with the help of 3D modeling through PLAXIS, Arup Singapore kept movement of the MRT structure to just 10 millimeters, even though excavation was just 6 meters away from the station wall. Additionally, ground settlement in the surrounding area was 20 millimeters, which is also well below required authority criteria. Incorporating the pile-raft model into PLAXIS 3D helped developers optimize pile penetrations and reduce the load on bored piles by 30% to 35%. Additionally, the model allowed Arup Singapore to optimize the thickness of the raft for each loading zone, given the nonuniform nature of the structure, both aboveground and belowground.

Construction on the Guoco Tower complex finished in 2016, and the tower has become one of the landmark structures in Singapore. Work on this project demonstrated how geotechnical applications and other advanced technology can drive engineering innovation. Arup Singapore's analysis and design work is expected to serve as a reference point for similar developments in the future.



Guoco Tower 3D Renderings and Visualizations



PLAXIS Sound Computation for Excavations and Foundations

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