

INNOVATIVE TOP-DOWN CONSTRUCTION OF THE NIAYESH UNDERGROUND PARKING

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ABSTRACT: Rapid urbanization in Tehran has created an urgent demand for large underground parking facilities to reduce surface congestion and improve traffic flow in highly constrained urban corridors. The Niayesh Underground Parking and Commercial Complex, located in District 3 of Tehran, represents one of the most complex deep excavation projects executed in close proximity to an operational urban highway tunnel. The project comprises nine underground parking levels, two above-ground commercial floors, approximately 1,275 parking spaces, and a final excavation depth of about 30.6 m. Severe site constraints, sensitive surrounding infrastructure, and complex geotechnical conditions rendered conventional excavation support systems impractical. Consequently, a full top-down construction methodology was adopted, enabling simultaneous excavation and permanent structural construction while controlling ground deformation and ensuring tunnel stability. Detailed geotechnical investigations confirmed dense alluvial and conglomeratic deposits with high stiffness, locally overlain by deep man-made fill. Staged finite element analyses using PLAXIS were carried out to evaluate soil-structure interaction and excavation performance. Maximum horizontal wall displacements of approximately 90 mm on the northern wall and 39 mm on the southern wall were predicted and verified by monitoring results, remaining within acceptable limits. This paper presents the adopted methodology, geotechnical conditions, numerical analyses, monitoring outcomes, and lessons learned, demonstrating the effectiveness of top-down construction for deep urban excavations integrated with existing tunnel infrastructure.

1. INTRODUCTION AND LITERATURE REVIEW

1.1 BACKGROUND

In dense metropolitan areas, the scarcity of available surface land has driven the expansion of underground infrastructure such as parking facilities, metro stations, and transport interchanges. Deep excavations in urban environments are frequently constrained by adjacent buildings, utilities, and operational tunnels, requiring strict control of ground movements and construction-induced deformations. Among available construction techniques, top-down construction has proven to be an effective solution for deep excavations exceeding 20–25 m, particularly where deformation control is critical. In this method, permanent slabs and columns are constructed progressively from the ground level downward while excavation proceeds beneath completed structural elements. Each slab acts as a horizontal strut, significantly increasing excavation stiffness and reducing wall deflection.

1.2 LITERATURE REVIEW

Early studies by Peck (1969) and Clough & O'Rourke (1990) emphasized the importance of excavation support stiffness and construction sequencing in controlling ground movements. Subsequent research demonstrated that early activation of permanent slabs in top-down systems can reduce lateral wall deflections by 30–50% compared with conventional braced excavations. More recent investigations have focused on the interaction between deep excavations and adjacent tunnels. Numerical and field studies by Kung et al. (2007), Goh et al. (2015), and Ng et al. (2018) showed that top-down construction significantly mitigates tunnel deformation when excavation occurs nearby. Advances in numerical modelling and monitoring have further enhanced the reliability of this method, enabling adaptive design and performance-based construction control.

1.3 OBJECTIVES AND SCOPE

This paper presents the Niayesh Underground Parking and Commercial Complex as a comprehensive case study of large-scale top-down construction integrated with an operational highway tunnel. The objectives are to describe the adopted top-down construction methodology; present the key geological

and geotechnical conditions; explain excavation sequencing and tunnel integration strategy; evaluate performance using numerical analysis and monitoring data; and summarize lessons learned for similar urban projects.

2. PROJECT DESCRIPTION

The Niayesh Underground Parking and Commercial Complex is located in District 3 of Tehran, adjacent to the Sadr–Niayesh urban highway tunnel system. The project includes: nine underground parking levels; two above-ground commercial floors; approximately 1,275 parking spaces; total built-up area of about 47,000 m²; and excavation depth of approximately 30.6 m. The site footprint is approximately 4,750 m² with a high occupancy ratio, leaving limited space for construction activities. Functional integration with the Niayesh tunnel provides direct vehicular access at tunnel level, significantly improving traffic circulation.

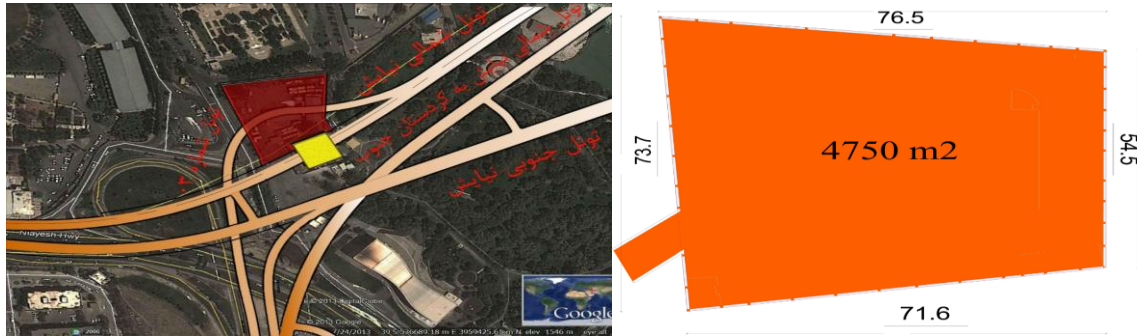


Figure 1: Site location and surrounding urban infrastructure

3. GEOLOGICAL AND GEOTECHNICAL CONDITIONS

3.1 GEOLOGICAL SETTING

The project is located within the northern Tehran alluvial fan system. Subsurface conditions are dominated by dense alluvial and conglomeratic deposits belonging to the Hezardareh (A) and Bn formations. These materials exhibit high stiffness, low compressibility, and high shear strength. A critical feature of the site is the presence of deep man-made fill on the eastern side, extending to depths of approximately 12–17 m. This fill zone shows greater variability in density and strength, increasing sensitivity to settlement and deformation.

3.2 SUBSURFACE INVESTIGATION AND SOIL PARAMETERS

The geotechnical investigation program included seven boreholes drilled to depths of approximately 23 m, supplemented by test pits and laboratory testing. Dominant soil classifications included GC, GM–GC, SC, and minor CL/ML layers. Groundwater was not encountered in the main boreholes, although localized perched water was anticipated in fill zones.

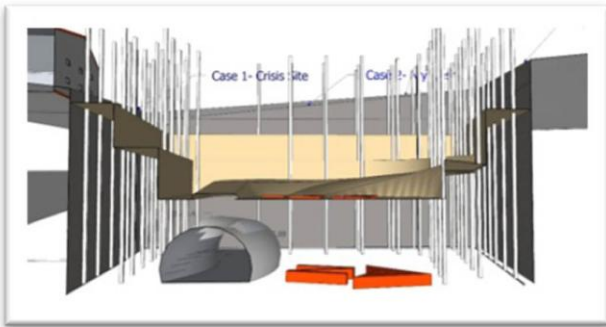
Table 1: Generalized soil profile and design parameters

Layer	Depth (m)	γ (kN/m ³)	ϕ' (°)	c' (kPa)	SPT (N)
Fill	0-12	17	30	10	8-15
GC-GM	12-23	19	36	30	15-30
GC	23-33	21	38	50	30-50
GP-GC	33-40	21	40	70	>50
SC/SM	40-45	20	34	5	20-40
CL/ML	45-50	18	28	15	10-30

4. SELECTION OF CONSTRUCTION METHOD

Several excavation support systems, including soil nailing, ground anchors, braced excavation, and piled shoring, were evaluated but rejected due to excessive predicted deformations, interference with the

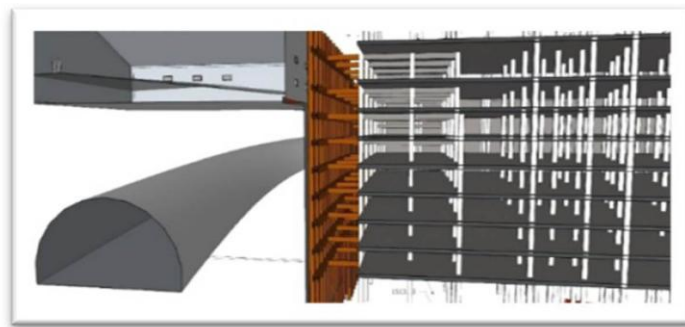
adjacent tunnel, and limited working space. A full top-down construction method was therefore selected as the only viable solution. Perimeter piles and internal columns were installed prior to excavation and served as both temporary and permanent structural elements, while sequential slab construction provided immediate lateral restraint to the excavation walls.



a) Surrounding Columns and Berms



b) Anchorage and Trusses



c) Top-Down Method

Figure 2: Comparison of excavation support options and selected top-down scheme

5. EXCAVATION, STRUCTURAL SYSTEM, AND TUNNEL INTEGRATION

Excavation was carried out in staged cycles beneath completed slabs. Excavated material was removed through a vertical shaft and transported through the existing tunnel to the western portal, minimizing surface traffic disruption. The total excavation volume was approximately 151,000 m³. Tunnel integration required controlled demolition of approximately 2,000 m³ of tunnel crown sections. Demolition was performed in carefully sequenced zones to avoid overstressing load-bearing elements and to limit vibration effects. Innovative structural solutions included prefabricated reinforced concrete columns, hanging reinforced concrete walls replacing boundary columns, and specialized sliding and folding shoring systems to avoid interference with excavation operations.

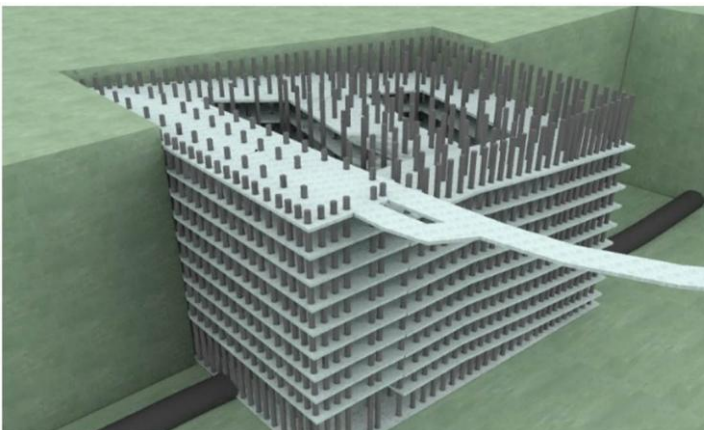


Figure 3: Cross-section of top-down excavation and slab sequence



Figure 4: Tunnel integration and controlled demolition zones

6. NUMERICAL ANALYSIS AND PERFORMANCE ASSESSMENT

Staged excavation and structural activation were simulated using PLAXIS 2D finite element analysis. A total of 43 construction stages were modelled to represent excavation, slab casting, column installation, and tunnel interaction. The analyses predicted maximum horizontal wall displacements of approximately 90 mm on the northern wall and 39 mm on the southern wall. Bending moments, shear forces, and axial forces obtained from the analyses governed the structural reinforcement design.

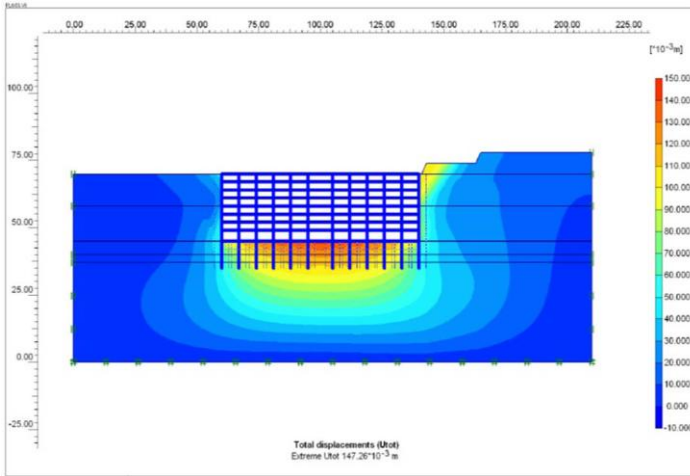


Figure 5: PLAXIS finite element model and mesh

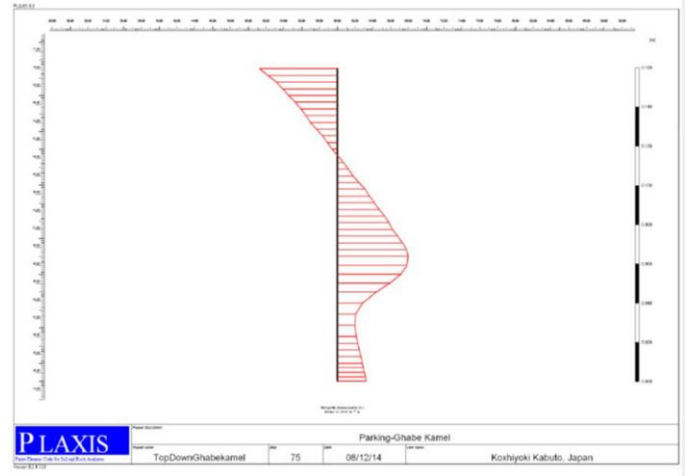


Figure 6: Calculated wall displacement profiles

7. MONITORING RESULTS

A comprehensive monitoring program was implemented, including periodic surveying of selected columns and retaining walls. Monitoring results confirmed that measured deformations were generally consistent with numerical predictions and remained within allowable limits. Localized higher settlements were observed at a limited number of points, primarily associated with fill zones and construction sequencing effects. However, these did not indicate progressive instability. The integration of monitoring data with numerical models enabled timely verification of performance and informed construction control decisions. Key lessons learned include the critical role of early slab activation, careful treatment of fill zones, and close coordination between excavation and tunnel operations.

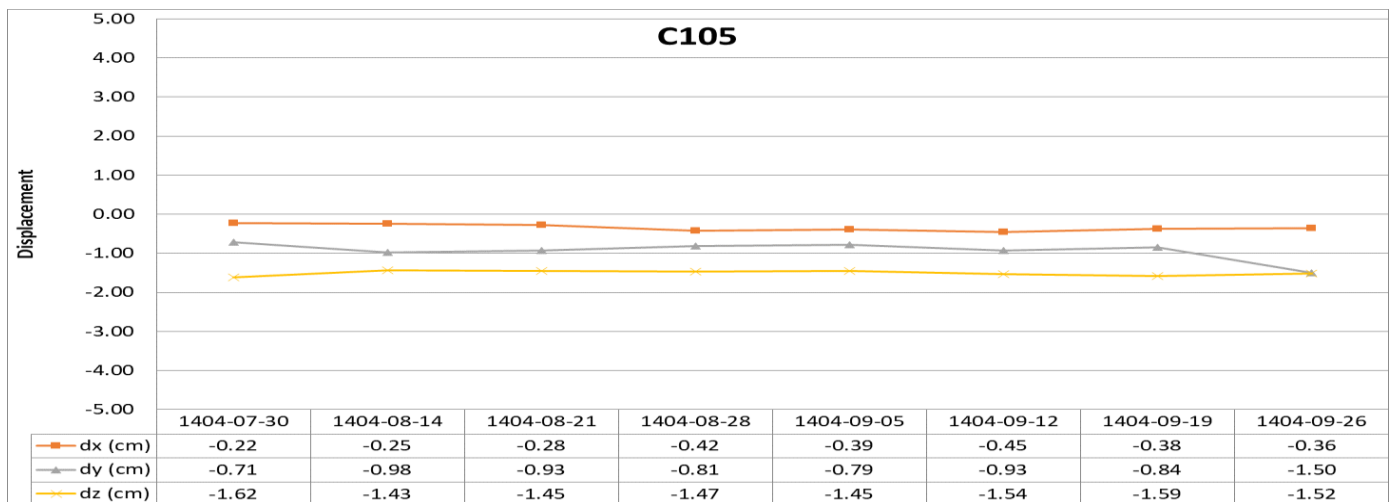


Figure 7: Example monitoring displacement trends

8. DISCUSSION OF MONITORING OUTCOMES AND PERFORMANCE INSIGHTS

The extensive monitoring campaign conducted throughout the construction of the Niayesh Underground Parking provided critical real-time data on structural behaviour, ground movements, and system interaction. This data not only validated the design assumptions but also offered actionable insights into the performance of the top-down construction method under complex urban constraints.

Table 2: Comparison of measured and allowable displacements

Direct	Point	$\Delta X,Y,Z$ (cm)	Δ allowable (cm)	Point	$\Delta X,Y,Z$ (cm)	Δ allowable (cm)
Z	C105	-0.81	-1.63	WS1	-0.10	-1.62
	C31	-0.60	-1.9	WW1	-2.24	-2.42
	C36	-1.67	-2.38	WW2	-2.28	-2.40
	C44	-0.88	-2	WN3	-1.84	2.00
	C48	-0.80	-2.10	C42	-2.17	-2.30
	C57	-0.43	-2.35	C53	-0.99	-2.26
	C93	-0.56	-2.13	C54	-1.10	-2.20
	C94	-1.92	-2.12	C40	0.03	-2.53
	C97	-0.83	-2.11	C103	-0.06	-1.58
	WE1	-0.16	-1.90	WN2	0.01	1.80

8.1 DEFORMATION PATTERNS AND COMPARISON WITH PREDICTIONS

Monitoring confirmed that lateral wall displacements were well controlled, with maximum recorded values remaining below the 90 mm (north) and 39 mm (south) thresholds predicted by PLAXIS 2D analyses. This alignment between predicted and measured behaviour underscores the reliability of the staged numerical modelling approach in simulating soil-structure interaction during top-down excavation. The early activation of permanent floor slabs as horizontal struts proved effective in limiting wall deflections, as evidenced by displacement trends that stabilized rapidly after each slab casting stage.

8.2 SETTLEMENT BEHAVIOUR IN CRITICAL ZONES

Vertical settlements were most pronounced in perimeter retaining walls and columns located within or adjacent to zones of deep man-made fill (e.g., WW1, WW2, WN3, C42, C94). These areas consistently exhibited settlements approaching 90–95% of their revised allowable limits, as identified in the monitoring reports. The fill material's variable density and compressibility contributed to higher and more uneven settlement responses. Notably, settlement trends in these critical zones did not show progressive acceleration, indicating that the structural system successfully redistributed loads and avoided uncontrolled deformation.

8.3 INTEGRATION OF MONITORING WITH ADAPTIVE DESIGN

The monitoring program enabled an adaptive design approach. When settlements in certain zones approached allowable limits, the structural model was recalibrated using SAP2000 to reflect the as-built conditions and updated loading stages. This allowed for the redefinition of permissible displacements based on actual site progress, avoiding unnecessary construction delays while ensuring safety. The process highlighted the importance of continuous feedback between monitoring data and analytical models in deep urban excavations.

8.4 IMPACT OF CONSTRUCTION SEQUENCING

Data revealed that settlement fluctuations correlated closely with construction activities such as soil excavation below slabs, temporary material stockpiling, and phased demolition of the adjacent tunnel crown. Recommendations derived from monitoring included stricter control over stockpile locations, faster backfilling of gaps between walls and slabs, and accelerated construction of perimeter foundation elements to reduce exposure time in unsupported conditions. These measures were implemented in later stages, contributing to stabilization of displacement rates.

8.5 STRUCTURAL AND GEOTECHNICAL SYNERGY

The success of the project hinged on the synergy between geotechnical control measures and structural detailing. The use of top-down construction minimized ground disturbance, while the inclusion of prefabricated columns and hanging walls provided additional stiffness where needed. Monitoring confirmed that internal columns experienced minimal differential settlement, preserving the integrity of the slab system. This synergy was particularly vital in areas close to the existing Niayesh tunnel, where vibration and deformation thresholds were stringent.

8.6 LESSONS FOR FUTURE PROJECTS

The Niayesh case demonstrates that robust monitoring is not merely a verification tool but a central component of the construction management system. Key takeaways include:

The necessity of high-frequency monitoring in fill-affected zones.

The value of integrating real-time data with finite element models to update allowable deformation limits.

The importance of sequencing and housekeeping in minimizing temporary loads on excavation supports.

The effectiveness of top-down construction in protecting adjacent sensitive infrastructure such as operational tunnels.

8.7 LONG-TERM MONITORING TRENDS AND PROJECT COMPLETION INSIGHTS

Extended monitoring through the final construction stages (up to September 2025) revealed key behavioural trends. As works progressed to the upper commercial floors, access to monitoring points became limited, reducing surveyed locations from 20 to four critical points (C105, WE1, WS1, and WE3). Despite this reduction, vertical settlement trends at previously critical locations (e.g., C105 and WE1) stabilized, reaching approximately 93–96% of revised allowable limits with no progressive increase over the preceding 12 months. This behaviour indicates that the structure reached a new equilibrium following completion of below-grade works, foundation construction, and perimeter backfilling.

Lateral displacements remained within acceptable limits. Although point WE3 temporarily exceeded the allowable displacement in the Y-direction, the magnitude decreased over time, indicating a non-progressive response. Overall, the monitoring results confirm satisfactory deformation control through project completion.

9. CONCLUSION

The Niayesh Underground Parking and Commercial Complex represents a landmark application of top-down construction integrated with an operational urban tunnel. Through rigorous geotechnical investigation, staged numerical analysis, innovative structural detailing, and continuous monitoring, a 30 m deep excavation was successfully executed under severe urban constraints. The project demonstrates that top-down construction can provide effective deformation control, enhanced safety, and operational flexibility for deep urban excavations adjacent to sensitive infrastructure. The lessons learned from this case study offer valuable guidance for future underground developments in congested metropolitan environments.

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