

# Journal of Engineering Research

ISSN 2764-1317

vol. 6, n. 4, 2026

## ... ARTICLE 1

Acceptance date: 04/05/2026

# COMPARATIVE TECHNICAL, ECONOMIC, AND SAFETY ANALYSIS OF TOP- DOWN AND BOTTOM-UP METHODS IN URBAN TRENCH EXCAVATIONS

## Vinicius Zamai Seva

Civil Engineer, graduated from Anhembi Morumbi University. Holds a postgraduate degree in Geotechnical Engineering from Paulista University. Currently pursuing an MBA in Project Management at the University of São Paulo

## Giovana Medeiros Seva

Civil Engineer, graduated from Anhembi Morumbi University



All content published in this journal is licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0).

**Abstract:** This paper presents a comparative technical, economic, and safety analysis between the Top-Down and Bottom-Up construction methods applied to the construction of underground subway stations in urban environments. The study is based on a representative hypothetical case located in the West Zone of the city of São Paulo, considering the geological and geotechnical conditions of the Resende Formation as determining factors in the selection of the construction method. The execution processes of each methodology, the risks associated with the excavation and shoring stages, and the technical criteria for selecting construction systems were evaluated. The direct cost analysis was based on SINAPI prices (March 2026, State of São Paulo) for conventional materials, and on estimates adjusted by the INCC-DI index for specialized services. The results indicate that the Top-Down method showed a reduction of approximately 18% in construction time and 4.6% in total direct cost compared to the Bottom-Up method. Regarding safety, the two methods presented equivalent overall scores (78 and 77, respectively), differing mainly in the nature of the risks: the Bottom-Up method concentrates moderate risks distributed throughout the entire project, while the Top-Down method introduces high-criticality risks in specific phases of confined excavation, requiring more rigorous control measures. The Top-Down method proved to be more suitable for the analyzed context, being especially recommended in densely populated urban areas where the reduction of surface disturbances and the control of deformations are critical factors.

**Keywords:** Top-Down construction; underground subway stations; diaphragm walls; urban excavations; risk analysis.

## Introduction

With urban densification, the implementation of underground infrastructure has become a necessary condition for transportation, sanitation, and supply systems in large cities. In this context, metro transportation stands out as a high-capacity mode capable of bypassing natural and man-made obstacles—such as changes in elevation, buildings, waterways, and other existing infrastructure—without disrupting the dynamics of the urban surface.

In Brazil, São Paulo was the first city to implement a metro line, whose construction began in 1968 and was completed in 1974, under the name North-South Line (Flores, 2024). Since then, São Paulo's subway system has expanded significantly, currently spanning over 111 km of track and 91 stations (Meier, 2026). Much of this work was carried out under diverse geological conditions (sedimentary soils of the São Paulo Tertiary Basin, Precambrian massifs, and Quaternary soils in crossings under major watercourses), requiring different engineering techniques for each situation (Carvalho, 2006).

Among the construction methods used for building cut-and-cover subway stations, two stand out in Brazilian and international practice: the conventional Bottom-Up method, in which construction proceeds from the lowest level toward the surface, and the inverted Top-Down method, in which the final structural slabs are progressively constructed from top to bottom, simultaneously serving as retaining elements and as the station's permanent structure. The choice between these methods is one of the most critical decisions in the development of projects of this na-

ture, as it determines the detailed design, direct costs, construction schedule, and safety risks to workers and the surrounding urban environment.

Although both methods are extensively documented in the technical literature, comparative studies that simultaneously consider the dimensions of cost, schedule, and safety, based on detailed quantities and updated price sources, are still scarce in the Brazilian context. This study seeks to fill this gap through comparative analysis applied to a representative hypothetical case in the West Zone of São Paulo, with a geological profile characteristic of the Resende Formation, near the Tietê River Basin.

The main objective of this study is to critically and quantitatively evaluate the performance of the Top-Down and Bottom-Up methods in terms of execution time, direct cost, and occupational safety, contributing to the technical basis for decision-making in urban underground infrastructure projects.

## Literature Review

### Open-Cut Construction Methods

Open-cut subway stations follow one of two approaches. In the Bottom-Up method, excavation proceeds to the deepest level, and the structure is built upward from there, as illustrated in Figure 1 (Shutterstock, 2024). In the Top-Down method, structural slabs are constructed progressively from top to bottom, serving simultaneously as permanent structural elements and as a retaining system for the excavation. This approach allows for the simultaneous construction of the superstructure and substructure, reducing the total construction time and increasing the rigidity of the support

system, which helps minimize deformations in the rock mass and adjacent structures (LI et al., 2014).

Figure 1 – Mechanized open-cut trenching – Bottom-Up Method



Source: Shutterstock (2024). License acquired by the authors.

The NATM (*New Austrian Tunnelling Method*) is also used in São Paulo, particularly for crossings through rock mass or competent residual soil, where shaft access and sequential excavation by working faces offer greater control over deformations (Domingues, 2016). This study is limited to open-cut methods, the dominant approach for large-scale stations on urban sedimentary soil.

### Retaining Systems

Deep trenches can be supported by sheet piles, side-by-side piles, soil nailing, or diaphragm walls. This study adopts the diaphragm wall, the most widely used solution in São Paulo Metro stations and the most suitable for the depths and geology of the case analyzed.

Construction begins with the excavation of each section using bentonite slurry, which stabilizes the cavity walls as the rectangular bucket excavator advances. Once the design depth is reached, the formwork is positioned and the concrete is poured, expelling the slurry—which is recovered

and reused in a closed-loop system (Joppert Junior, 2007). A significant advantage: the diaphragm wall can be incorporated into the station's permanent structure, eliminating temporary elements and reducing construction time and material consumption.

## Geological Constraints

The Resende Formation, predominant in the West Zone of São Paulo, consists of clayey and sandy sediments of low to medium strength, with a frequently shallow water table (Kutner; Bjornberg, 1997). In soils with these characteristics, the risk of settlement in neighboring structures is real, and deformation control becomes a criterion as relevant as cost in the choice of construction method (Massad, 2005).

## Risk Analysis in Urban Excavations

Deep excavations in urban areas expose workers and adjacent buildings to geotechnical, structural, and occupational risks. NBR 9061 defines the minimum requirements for safe execution: design of retaining structures, control of groundwater level lowering, and protection of nearby structures. NR-18 addresses working conditions in civil construction, with specific requirements for confined spaces. This condition is created by the Top-Down method from the moment the roof slab is poured, when excavation activities begin to occur entirely below the surface.

## Methodology

The methodology adopted is based on a comparative analysis of the Top-Down and Bottom-Up construction methods applied to the construction of subway stations in an urban environment. The study was developed based on a review of specialized technical literature, supplemented by the definition of a representative hypothetical case and a comparative analysis of the two methodologies across three dimensions: construction timeline, direct cost, and occupational safety.

To enable comparison under equivalent conditions, a representative hypothetical case was defined for a subway station in the West Zone of São Paulo, with a geological profile characteristic of the Resende Formation, near the Tietê River Basin. The station was designed to be approximately 132 m long, 27 m wide, and 26 m deep, with diaphragm wall retaining structures supported by the permanent structure. The structure was designed with 80 cm thick cast-in-place slabs, reinforced in a single direction ( $I_y/I_x > 2$ ), with few beams due to structural requirements, verified based on Table 6 of ABNT NBR 15200:2012. No lowering of the external water table was anticipated for the excavation scenario analyzed.

The comparative schedules were prepared based on a technical estimate grounded in the authors' experience with similar infrastructure projects and on standard productivity parameters adopted in works of this nature. The activities considered included preliminary services, retaining structures, trench excavation, structural construction, installations and systems, architecture, and landscaping. The schedules do not correspond to a specific detailed design but are simplified models for comparative purposes.

The cost estimate was based on the main inputs and services involved in the execution of the project. For conventional materials (concrete and steel), SINAPI prices (March 2026, State of São Paulo) were used. For specialized services not directly covered by SINAPI (diaphragm wall excavation, tie rods, and specific Top-Down operations), estimates from previous projects were used, adjusted by the INCC-DI index (FGV) for the period from December 2022 to March 2026.

The risks associated with the main activities of each method were identified and assessed using a probability and consequence matrix, with explicit classification criteria based on the principles of ISO 31000:2018. The identification of risk events was guided by the guidelines of NR-18 and the technical requirements of NBR 9061, applicable to open-cut excavations.

## Construction Sequences

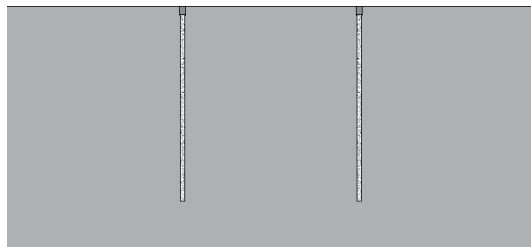
Based on the construction methods previously presented, this section describes the execution stages associated with the Bottom-Up and Top-Down methodologies applied to the construction of open-cut subway stations. The appropriate choice of construction method and rigorous monitoring during execution are critical for preventing damage to neighboring structures, especially in densely populated urban areas (Ou et al., 1998).

### Bottom-Up Method

Conventional open-cut construction is a method that involves excavating down to the lowest design level and then constructing the permanent structures. Thus, the method can be summarized as follows:

In the first phase, the retaining structures are constructed (Figure 2), which can vary, such as diaphragm walls (as in the subject of this study), driven steel or concrete sheet piles, among others.

Figure 2 – Schematic of the First Phase – Construction of Retaining Structures

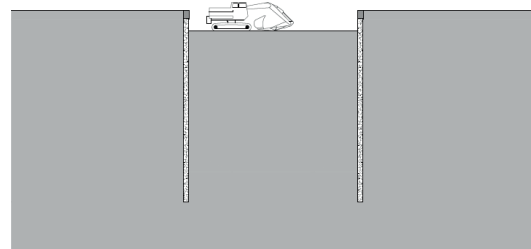


Source: Authors (2026).

Excavation containment was addressed using diaphragm walls, as described in the Theoretical Framework section.

Once the retaining structures are complete, the next phase (Figure 3)—excavation of the interior of the trench—can begin.

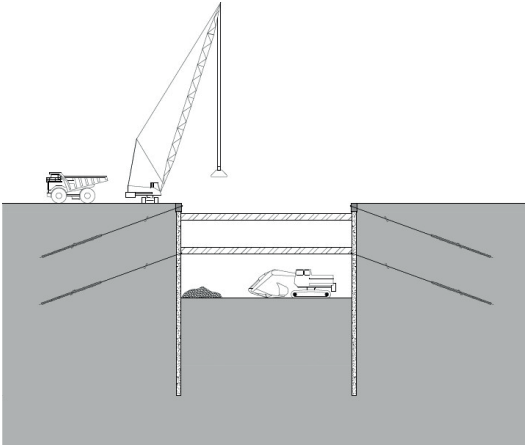
Figure 3 – Schematic of the Second Phase – Excavation of the Trench Interior



Source: Authors (2026).

In this method, a counterbalancing structure is required, consisting of struts and/or tie rods (Figure 4).

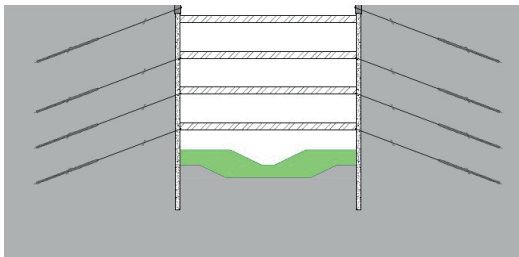
Figure 4 – Schematic of the Third Phase – Installation of Counterbalancing Structures



Source: Authors (2026).

Once the bottom elevation of the trench is reached, the bottom slab is then constructed and work begins on the station's permanent structures (beams, slabs, columns) (Figure 5). As construction progresses, always from the bottom up, the struts can be removed and the tie rods deactivated.

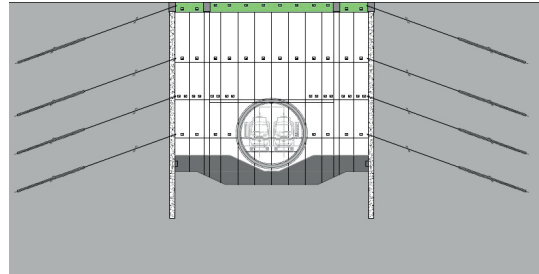
Figure 5 – Schematic of Phase Four – Construction of the Bottom Slab



Source: Authors (2026).

Finally, the top slab is constructed, thus completing the civil works (Figure 6).

Figure 6 – Schematic of the Fifth Phase – Construction of the Station's Permanent Structures



Source: Authors (2026).

### ***Benefits of the Bottom-Up Method***

The main advantage of the Bottom-Up method is its simplicity of execution. The bottom-up construction sequence is familiar to the vast majority of construction teams, reducing the learning curve and facilitating quality control at each stage. Since it does not rely on specialized equipment for confined excavation, its operation is compatible with a broader supplier market, which enhances competitiveness in the contracting processes.

Access to the excavation is direct and unrestricted throughout the earthwork phase, allowing the use of large conventional equipment (excavators, dump trucks, and compactors) without the dimensional limitations imposed by confinement under a slab. This feature also facilitates geometric control of the excavation, visual inspection of the retaining structures, and monitoring of settlement in adjacent structures.

In contexts where geological conditions are favorable (competent soils, deep water table, and low density of surrounding buildings), the Bottom-Up method may represent the solution with the lowest cost and lowest operational risk, eliminating the need for investment in forced ventilation systems and the specific confined space work procedures required by the inverted method (OU et al., 1998).

## Challenges of the Bottom-Up Method

The main limitation of the Bottom-Up method is the prolonged impact on the urban surface. Since the excavation remains open throughout virtually the entire construction period, road closures, interference with utility networks, and restrictions on pedestrian and vehicle traffic extend throughout the entire structural phase, which, in the case studied, corresponds to the longest period of the schedule.

The reliance on temporary shoring systems (steel struts and prestressed tie rods) introduces additional costs for installation, monitoring, and decommissioning, in addition to representing elements that dictate the construction sequence and require structural verification at each excavation phase. The progressive removal of these elements as the structure progresses imposes restrictions on the pace of execution and increases the number of critical interfaces on the job site.

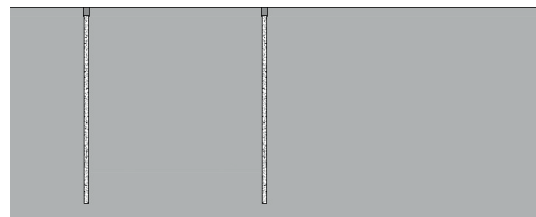
In low-strength soils with a shallow water table (conditions characteristic of the Resende Formation in the West Zone of São Paulo), controlling lateral deformations of the retaining structures and surface settlements is more demanding in the Bottom-Up method than in the Top-Down method, since the stiffness of the temporary shoring system is lower than that provided by the permanent structural slabs. Numerical and field studies confirm that this difference in stiffness is the main factor responsible for the greater volume of displacements observed in the conventional method under soft soil conditions (LI et al., 2014).

## Top-Down Method

While in the traditional construction method, construction begins with earthwork, excavation, and disposal of excess material, and ends with the final structure, the Inverted (Top-Down) Method proposes excavating a small layer of soil (generally between 0.80 and 2.00 m) and constructing the concrete slab that will serve as the counterweight for the retaining structure. After this slab is built, the surface is made available in a significantly shorter period than that achieved by the conventional open-cut trenching method, which allows work to proceed on the construction of the other station structures. The construction process is described in more detail in the following phases.

The first phase involves initial work, such as earthmoving and setting up the construction site, in addition to retaining wall activities (diaphragm wall or other methods mentioned earlier) and lowering the water table (Figure 7), if necessary, to optimize the retaining structures, since one of the advantages of the Top-Down method is the ability to work in dry conditions, even in saturated soils, as there is no need to install tie rods.

Figure 7 – Schematic of the First Phase – Auxiliary Services and Retaining Structure Construction

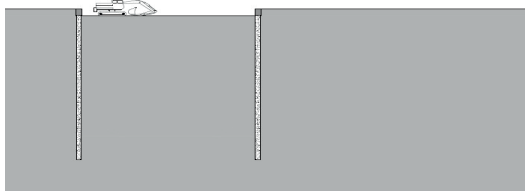


Source: Authors (2026).

In the second phase (Figure 8), after completion of the retaining structures, earthwork can begin for the construction of the

station's roof slab, excavating down to the bottom elevation of the slab and pouring the structure at ground level.

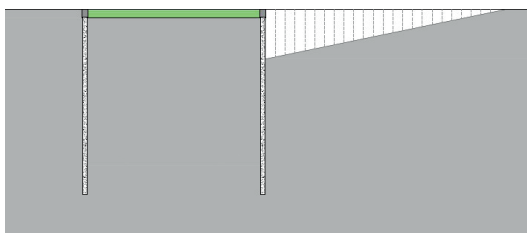
Figure 8 - Schematic of the Second Phase - Excavation for Construction of the Roof Slab



Source: Authors (2026).

In the third phase (Figure 9), with the completion of the concrete pour for the roof slab—which will serve as the first counterweight—excavation begins on the external access ramp for machinery to start excavations of the main trench and remove excess soil. It is important to note that the construction of the ramp is not mandatory. A crane can be used to remove the material, as in conventional methods, through openings in the structure; however, this results in a loss of efficiency, since with a ramp, work above the slab—such as access roads, technical buildings, landscaping, and roadways—can begin immediately. In cases where space is limited, road areas can be used and restored in a very short time, immediately after the roof slab is completed.

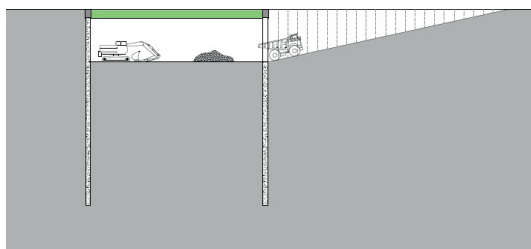
Figure 9 - Schematic of the Third Phase - Pouring of the Roof Slab and Construction of the Access Ramp



Source: Authors (2026).

In the fourth phase (Figure 10), excavation begins inside the trench down to the level of the next slab (such as the ticket office slab), carried out beneath the constructed roof, while the upper-level work is also being performed.

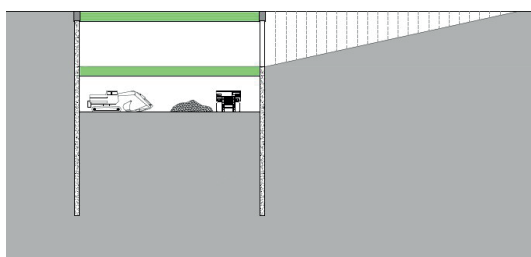
Figure 10 - Schematic of the Fourth Phase - Excavation Under the Roof Slab to the Level of the Next Slab



Source: Authors (2026).

Once the next slab is poured, excavation of the slab immediately below can begin (Figure 11), and so on. Access to the lower levels is provided by ramps inside the trench. Excavation proceeds to the elevation of the next slab, which will serve as a counterbalance for the next advance.

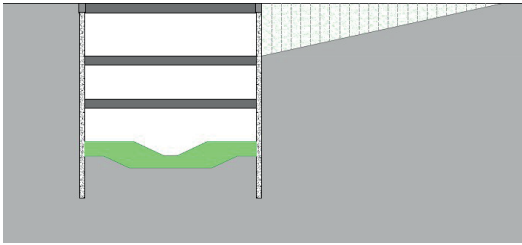
Figure 11 - Schematic of Phase Five - Excavation of the Lower Levels of the Trench



Source: Authors (2026).

Upon reaching the final advance level, the final excavation begins, shaping the geometry of the area that will encompass the station's bottom slab through earthworks (Figure 12), followed by concrete placement (Phase 6).

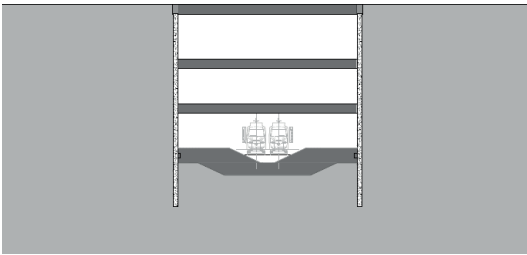
Figure 12 - Schematic of Phase Six - Final Earthwork and Concrete Pouring of the Station Floor Slab



Source: Authors (2026).

With the completion of the bottom slab construction phase, the civil works of the station executed using the Top-Down methodology can be considered finished. From this point on, the seventh phase, the finishing and systems installation phase covering the metro line can begin (Figure 13).

Figure 13 - Schematic of the Seventh Phase - Finishing and Systems Installation



Source: Authors (2026).

### ***Benefits of the Top-Down Method***

The main advantage of the Top-Down method is the possibility of overlapping the excavation and structural construction phases. The roof slab, poured in the early stages of the project, allows excavation, reinforcement, concrete pouring, and finishing teams to operate simultaneously at different levels (above and below the surface), significantly reducing the total construction time compared to the conventional method.

The absence of temporary shoring systems (tension rods and metal struts) directly reduces installation, monitoring, and decommissioning costs, while also eliminating the construction sequencing restrictions imposed by the progressive removal of these elements. Access for equipment and materials into the excavation is facilitated by ramps, eliminating the need for gantries and increasing the productivity of underground work fronts.

A significant advantage in urban contexts is the rapid return of the surface to public use. Immediately after the casting of the roof slab, road traffic can resume, and landscaping, access roads, and technical structures can be constructed on the surface, even while excavation of the lower levels is still underway. In locations with severe space constraints, this feature can be decisive for the project's feasibility.

Field studies and numerical analyses indicate that the Top-Down method performs better in controlling lateral displacements of retaining structures and ground settlement, especially in densely populated urban and n areas, where soil-structure interaction is critical (Li et al., 2014). This characteristic is particularly relevant in the geological conditions of the Resende Formation, where low-strength clay soils amplify the effects of open excavations on adjacent structures.

### **Challenges of the Top-Down Method**

The main limitation of the Top-Down method is the operational complexity imposed by the confined environment. Once the roof slab is poured, all excavation activities take place in an enclosed space, requiring smaller equipment adapted to dimensional

constraints, forced ventilation systems, and permanent artificial lighting. This condition increases operational costs and demands more rigorous logistical planning than the conventional method.

Structural verification of the slabs during the intermediate phases is more complex than in the Bottom-Up method, since each slab must be designed not only for the permanent loads of the final structure but also for the shoring stresses generated during subsequent excavation phases—a condition that does not always correspond to the final loading state and requires specific analysis for each construction phase.

Workers involved in confined excavation operations must be trained in accordance with the requirements of NR-18 and NR-33, which regulate safety conditions in confined spaces. The issuance of a Entry and Work Permit (PET), continuous monitoring of air quality, and the availability of emergency and rescue teams are regulatory requirements that introduce additional costs and procedures not present in the Bottom-Up method.

It should also be noted that the time interval between excavation stages can significantly influence soil behavior, since the dissipation of neutral pressures and creep effects contribute to the progressive increase in displacements and settlements over time (Ou et al., 1998). This phenomenon reinforces the need for continuous geotechnical monitoring throughout the entire underground excavation phase.

## Comparative Analysis

### Schedule Performance

The comparative analysis of construction schedules between the Bottom-Up and Top-Down construction methods was conducted by developing representative construction schedules for the construction of an underground subway station in an urban environment. The schedules presented were developed based on our own technical estimates, grounded in the authors' experience with similar infrastructure projects, as well as on standard productivity parameters adopted in works of this nature.

To define the durations of the activities, the main services involved in the execution of the project were considered, including preliminary work, retaining structures (diaphragm walls), trench excavation, structural work, installations and systems, as well as the final stages of architecture and landscaping. The productivity rates adopted reflect typical market values and were adjusted to represent a realistic and comparable scenario between the two methodologies analyzed. It should be noted that the schedules presented do not correspond to a specific detailed design, but rather to a simplified model for comparative purposes.

It can be observed that, in the Bottom-Up method, activities predominantly follow a sequential logic, in which the construction of the structure depends on the completion of the excavation and shoring stages, resulting in less overlap of work fronts. On the other hand, in the Top-Down method, there is an alternation and overlap between the excavation and structural execution stages, since the intermediate slabs and the roof



## Direct Costs

For the direct cost analysis, a comparative approach was adopted between the Top-Down and Bottom-Up construction methods, based on an overall estimate of the main inputs and services involved in the construction of subway stations in an urban environment. The quantification of services was adjusted to the case study under consideration, allowing for a consistent evaluation of the two methodologies under equivalent conditions.

The unit costs used were obtained from two main sources. For conventional materials, such as concrete and steel, values from the SINAPI (National System for Research on Construction Costs and Indices) database were adopted, using the most recent reference available (March 2026, State of São Paulo), ensuring traceability and alignment with market rates. For construction services and systems not directly covered by SINAPI (such as diaphragm wall excavation, installation of tie rods, and specific operations associated with the Top-Down methodology), values based on project estimates and previous technical references were used, monetarily adjusted by the INCC-DI index (FGV), for the period between December 2022 and March 2026.

This combined approach allowed for the construction of a consistent cost basis, reconciling standardized official data with representative estimates for specialized services, maintaining methodological consistency and avoiding duplicate value adjustments.

Tables 2 and 3 present direct cost estimates for the Bottom-Up and Top-Down methods, respectively, considering the main structural, geotechnical, and operational items involved in the execution of the project.

As shown in Table 4, the results indicate that, under the specific conditions of this study, the application of the Top-Down methodology resulted in an approximate 4.6% reduction in the total direct cost of the project. This difference is primarily associated with the optimization of construction phases, the reduction of operational interferences, and the reduced need for temporary support systems during certain phases of execution.

Table 4 – Comparison of Direct Costs

Top-Down Methodology	Bottom-Up Methodology
R\$ 140,139,353.48	R\$ 146,936,130.01

It should be noted that the results presented are subject to the assumptions adopted in the study, including local geotechnical characteristics, the station's structural layout, and the assumptions regarding the quantification of services; they should not be generalized to all project situations without a specific analysis. Additionally, the cost values used represent estimates based on specific references (SINAPI and updates by INCC) and are applicable exclusively to the context analyzed in this study. These values may vary significantly depending on factors such as geographic location, market conditions, material availability, and the specific construction characteristics of each project.

## Occupational Safety and Risk

The safety analysis of the construction methods was conducted by identifying and evaluating the main risks associated with the execution stages of each methodology, covering the processes of excavation, retaining structure construction, concrete placement, and anchoring. The assessment adopted a qualitative risk analysis approach, structured as a probability-consequence matrix, consistent with the risk

Table 2 – Cost Analysis – Bottom-Up Methodology

Bottom-Up Methodology					
Item	Unit	Qty	Unit Price	Reference	Total
CA-50 Steel – Supply and Installation	t	5,128.50	R\$ 8,200.00	SINAPI-SP 03/2026	R\$ 42,053,700.00
15 MPa concrete	m <sup>3</sup>	977.03	R\$ 500.00	SINAPI-SP 03/2026	R\$ 488,515.00
25 MPa concrete	m <sup>3</sup>	12,495.19	R\$ 560.00	SINAPI-SP 03/2026	R\$ 6,997,306.40
30 MPa concrete	m <sup>3</sup>	740.78	R\$ 620.00	SINAPI-SP 03/2026	R\$ 459,283.60
35 MPa concrete	m <sup>3</sup>	19,272.33	R\$ 700.00	SINAPI-SP 03/2026	R\$ 13,490,631.00
40 MPa concrete	m <sup>3</sup>	0.00	R\$ 579.20	INCC-DI Dec 2022 → Mar 2026	R\$ -
Diaphragm Wall Excavation	m <sup>3</sup>	12,112.64	R\$ 450.74	INCC-DI Dec 2022 → Mar 2026	R\$ 5,459,651.35
Excavation of Trenches and Underground Stations	m <sup>3</sup>	98,045.42	R\$ 376.40	INCC-DI Dec 2022 → Mar 2026	R\$ 36,904,296.09
Mechanical Excavation	m <sup>3</sup>	3,443.19	R\$ 179.24	INCC-DI Dec 2022 → Mar 2026	R\$ 617,157.38
Spreading of Soil	m <sup>3</sup>	110,695.02	R\$ 255.28	INCC-DI Dec 2022 → Mar 2026	R\$ 28,258,224.71
Continuous flight auger pile, 50 cm diameter	m	240.00	R\$ 140.26	INCC-DI Dec 2022 → Mar 2026	R\$ 33,662.40
Form for Stations and Buildings	m <sup>2</sup>	23,797.63	R\$ 30.83	INCC-DI Dec 2022 → Mar 2026	R\$ 733,680.93
Supply and Installation of Pre-cast Elements	m <sup>3</sup>	0.00	R\$ 1,862.18	INCC-DI Dec 2022 → Mar 2026	R\$ -
Concrete Placement	m <sup>3</sup>	20,801.77	R\$ 35.58	INCC-DI Dec 2022 → Mar 2026	R\$ 740,126.98
120 T Struts - Fixed Cost	each	12.00	R\$ 1,606.30	INCC-DI Dec 2022 → Mar 2026	R\$ 19,275.60
120 T Brackets - Linear Cost	m	360.00	R\$ 476.50	INCC-DI Dec 2022 → Mar 2026	R\$ 171,540.00
Earth Transport	m <sup>3</sup> xkm	3,304,741.69	R\$ 3.18	INCC-DI Dec 2022 → Mar 2026	R\$ 10,509,078.57
<b>Total</b>					R\$ 146,936,130.01

Table 3 – Cost Analysis – Top-Down Methodology

Top-Down Methodology					
Item	Unit	Qty	Unit Price	Reference	Total
CA-50 Steel – Supply and Installation	t	4,698.74	R\$ 8,200.00	SINAPI-SP 03/2026	R\$ 38,529,668.00
15 MPa concrete	m <sup>3</sup>	1,146.86	R\$ 500.00	SINAPI-SP 03/2026	R\$ 573,430.00
25 MPa concrete	m <sup>3</sup>	12,495.19	R\$ 560.00	SINAPI-SP 03/2026	R\$ 6,997,306.40
30 MPa concrete	m <sup>3</sup>	188.37	R\$ 620.00	SINAPI-SP 03/2026	R\$ 116,789.40
35 MPa concrete	m <sup>3</sup>	0.00	R\$ 700.00	SINAPI-SP 03/2026	R\$ -
40 MPa concrete	m <sup>3</sup>	13,729.87	R\$ 579.20	INCC-DI Dec 2022 → Mar 2026	R\$ 7,952,340.70
Diaphragm Wall Excavation	m <sup>3</sup>	12,112.64	R\$ 450.74	INCC-DI Dec 2022 → Mar 2026	R\$ 5,459,651.35
Excavation of Trenches and Underground Stations	m <sup>3</sup>	102,591.61	R\$ 376.40	INCC-DI Dec 2022 → Mar 2026	R\$ 38,615,482.00
Mechanical Excavation	m <sup>3</sup>	3,443.19	R\$ 179.24	INCC-DI Dec 2022 → Mar 2026	R\$ 617,157.38
Spreading of Soil	m <sup>3</sup>	114,704.25	R\$ 255.28	INCC-DI Dec 2022 → Mar 2026	R\$ 29,281,700.94
Continuous flight auger pile, 50 cm diameter	m	0.00	R\$ 140.26	INCC-DI Dec 2022 → Mar 2026	R\$ -
Form for Stations and Buildings	m <sup>2</sup>	16,987.60	R\$ 30.83	INCC-DI Dec 2022 → Mar 2026	R\$ 523,727.71
Supply and Installation of Pre-cast Elements	m <sup>3</sup>	0.00	R\$ 1,862.18	INCC-DI Dec 2022 → Mar 2026	R\$ -
Concrete Placement	m <sup>3</sup>	14,876.73	R\$ 35.58	INCC-DI Dec 2022 → Mar 2026	R\$ 529,314.05
120 T Tie Rods - Fixed Cost	un	0.00	R\$ 1,606.30	INCC-DI Dec 2022 → Mar 2026	R\$ -
120 T Brackets - Linear Cost	m	0.00	R\$ 476.50	INCC-DI Dec 2022 → Mar 2026	R\$ -
Earthwork	m <sup>3</sup> xkm	3,441,127.53	R\$ 3.18	INCC-DI Dec 2022 → Mar 2026	R\$ 10,942,785.55
<b>Total</b>					<b>R\$ 140,139,353.48</b>

Table 5 – Probability classification criteria

Level	Probability	Definition
1	Low	Rare event: occurs in less than 10% of similar projects or requires atypical conditions to occur
2	Medium	Occasional event: already recorded in similar projects under normal execution conditions
3	High	Frequent event: expected under normal construction conditions, with a recurring history in the sector

Table 6 – Consequence classification criteria

Level	Consequence	Definition
1	Minor	Incident without time-off: first aid provided on-site, with no lasting effects
2	Moderate	Accident requiring medical attention: reversible injury requiring medical treatment
3	Severe	Serious or fatal accident: irreversible, disabling, or life-threatening injury

Table 7 – Risk Level Determination Matrix

Prob \ Consequence	Low (1)	Moderate (2)	Severe (3)
Low (1)	1	2	3
Medium (2)	2	4	6
High (3)	3	6	9

Table 8 – Acceptability and Action Criteria

Score	Classification	Action Guideline
1–3	Low	Monitor: standard safety procedures are sufficient
4–6	Medium	Control: requires specific preventive measures before starting the activity
7–9	High	Eliminate or mitigate immediately: activity should not be started without controls in place

Table 9 – Risk level for the Bottom-Up method

Location	Risk	Bottom-Up Method		
		Probability	Severity	Total Risk
Trench Excavation	Pinch	2	3	6
	Collapse	2	3	6
	Collapse of existing structures	2	2	4
	Lack of oxygen	1	2	2
	Noise	3	2	6
Containment	Falling objects	3	1	3
	Cuts	3	2	6
	Scams	2	2	4
Concrete work	Falling objects	1	2	2
	Falling from a height	2	3	6
	Level drop	2	2	4
	Particle protection	1	3	3
	Vibration	2	2	4
	Overloads	3	3	9
Anchoring	Cuts	3	2	6
	Drop	2	2	4
	Zone of instability	3	1	3
<b>Total Global Risk</b>				<b>78</b>

Table 10 – Risk Level for the Top-Down Method

Local	Risk	Top-Down Method		
		Probability	Severity	Total Risk
Trench Excavation	Pinch	1	3	3
	Collapse	1	3	3
	Collapse of existing structures	1	2	2
	Lack of oxygen	3	3	9
	Noise	3	3	9
Containment	Falling objects	3	1	3
	Cuts	3	2	6
	Strikes	2	2	4
Concrete work	Falling objects	2	2	4
	Falling from a height	2	3	6
	Level drop	2	2	4
	Particle protection	3	3	9
	Vibration	2	3	6
	Overloads	3	3	9
Anchoring	Cuts	N/A	N/A	N/A
	Drop	N/A	N/A	N/A
	Instability zone	N/A	N/A	N/A
<b>Total Global Risk</b>				<b>77</b>

\* Anchoring section excluded from the Top-Down total — the method does not use tie rods, with counterbalancing provided by the permanent structural slabs.

management principles established by ISO 31000:2018. The identification of risk events was based on the guidelines of NR-18, which regulates occupational safety and health conditions in civil construction, and on the technical requirements of NBR 9061, applicable to open-cut excavations.

For risk classification, explicit probability and consequence criteria were defined, as presented in Tables 5 and 6. Probability levels were established in three categories, based on the frequency of occurrence observed in underground infrastructure projects of similar scale. Consequences were classified into three levels, considering the potential impacts on workers' physical integrity.

The risk level is calculated as the product of the probability and consequence indices, according to the classification matrix presented in Table 7. The resulting scores were grouped into three severity categories, each associated with action and control guidelines, as shown in Table 8.

The assignment of probability and severity levels to each risk was based on technical literature and the typical characteristics of each construction method. For the most critical risks (excavation collapse, ventilation deficiencies in confined spaces, and overexertion), the recommendations of NBR 9061 regarding the stability of retaining structures and the requirements of NR-18 for work in confined spaces and exposure to physical agents were considered. Tables 9 and 10 present a comparison of risk levels between the Bottom-Up and Top-Down methods.

The results reveal that the two methods have similar overall scores (78 for Bottom-Up and 77 for Top-Down), indicating that the aggregate quantitative difference is marginal.

However, interpreting the numerical total in isolation is insufficient: the nature and distribution of risks differ significantly between the methodologies, and this distinction is the most relevant finding of the analysis.

The Bottom-Up method focuses its exposure on risks with medium to high probability and moderate to severe consequences, distributed throughout virtually the entire project: collapses, entrapments, falling existing structures, and noise in open areas. These are recurring risks, controllable through standard procedures, but present on all work fronts simultaneously. The anchoring section, unique to this method, adds three additional risk categories (total score of 13 points) with no equivalent in the Top-Down approach.

Top-Down, in turn, eliminates the risks of open excavation instability and entirely eliminates the use of tie rods, but introduces three events with a score of 9 ( : lack of oxygen, noise in confined spaces, and particle protection), all classified as high and requiring elimination or mitigation before the start of the activity. These risks are concentrated in the phases of excavation beneath slabs and require more complex control measures: forced ventilation systems, continuous air quality monitoring, and respiratory protection equipment certified for confined spaces, in accordance with NR-33 and NR-18.

In summary: the Bottom-Up approach distributes moderate risks throughout the entire project; the Top-Down approach concentrates severe risks in specific phases, but with lower cumulative exposure in the other stages. The choice of the safest method therefore depends on the team's operational capacity to manage high-criticality risks on a case-by-case basis, and not solely on the aggregate overall score.

It is worth noting that the assigned values are qualitative and comparative in nature, being applicable to the specific context of this study. Detailed quantitative analyses, such as Preliminary Risk Analysis (PRA) or FMEA adapted to excavations, are recommended for real projects as a complement to the assessment presented here.

## Discussion

The results obtained in this study are consistent with what the international literature reports for similar geotechnical conditions. The 18% reduction in construction time associated with the Top-Down method aligns with the findings of Li et al. (2014), who documented significant schedule gains in urban projects where the overlap between excavation and structural construction was systematically exploited. It should be noted, however, that actual schedule gains in the field depend critically on the ability to manage multiple simultaneous work fronts, an operational variable that the comparative model of this study does not fully capture, given its hypothetical nature.

The 4.6% difference in direct cost, although modest in percentage terms, represents a nominal savings of approximately R\$ 6.8 million under the analyzed conditions. This figure is explained by the elimination of tie rods and the reduction in formwork consumption, factors whose impact is amplified in large-scale, long-duration projects. In projects with shallower depths or more competent soils ( ), this difference tends to decrease; conversely, in deeper projects or those with a greater number of intermediate slabs, the economic advantage may be more significant. This behavior indicates that the cost analysis is sensitive to the station's ge-

ometry and that generalizations should be made with caution. Regarding safety, the closeness of the overall scores—78 for Bottom-Up and 77 for Top-Down—warrants careful interpretation. Ou et al. (1998) had already noted that the Top-Down method, by replacing temporary shoring systems with permanent slabs, significantly reduces the risks associated with the instability of open excavations.

The results of this study confirm this trend: the risks of collapse and falling of existing structures have a reduced probability in the Top-Down method due to the system's greater rigidity. However, the introduction of three events with a maximum score (9) related to the confined environment, lack of oxygen, noise, and exposure to particles, represents a shift in the risk profile, not necessarily an absolute improvement. The safety of the Top-Down method is, therefore, highly dependent on the maturity of the safety management system of the execution team, especially regarding compliance with the confined space work requirements established by NR-33.

An aspect often overlooked in comparative models is the cost of mitigating confined space risks, which is not accounted for in the direct cost analysis of this study. Forced ventilation systems, air quality monitoring, and specific training for confined spaces represent real costs that, if incorporated, could reduce or eliminate the economic advantage of the Top-Down method. This limitation reinforces the need for integrated analyses that consider direct costs, risk control costs, and timelines together.

Finally, the Resende Formation—low- to medium-strength clay soils with a shallow water table—represents one of the most favorable scenarios for applying the

Top-Down method in Brazil. In formations with higher resistance, such as residual gneiss or diabase soils found in other metropolitan regions, the advantage in deformation control would be less pronounced, and the results presented here cannot be directly extrapolated.

## Conclusions

Overall, the results indicate that the top-down method performs better in the context analyzed, offering simultaneous advantages in terms of schedule and direct costs, as well as a compatible risk profile, provided it is accompanied by a specific control plan for confined spaces. Its application is especially recommended in densely populated urban areas, where minimizing surface disturbances and controlling deformations in adjacent structures are critical factors for the project's feasibility.

The results are contingent upon the assumptions adopted (particularly the hypothetical nature of the case study, the estimated productivity rates, and the geo-technical profile of the Resende Formation) and should not be generalized to other projects without a proper analysis of the specific conditions of each project. The main limitation of this study is the lack of validation with data from an actual completed project, which presents an opportunity for future research.

In this regard, the following are recommended as next steps: the application of the comparative methodology to real-world cases with available detailed design data; the incorporation of quantitative risk analyses, such as APR or FMEA adapted to urban excavations; and the extension of the comparison to other geological contexts repre-

sentative of the Brazilian territory, such as residual gneiss soils and altered diabase profiles, common in other metropolitan regions of the country.

## References

BRAZILIAN ASSOCIATION OF TECHNICAL STANDARDS. **NBR 9061**: Safety of open-cut excavation. Rio de Janeiro: ABNT, 1985.

BRAZILIAN ASSOCIATION OF TECHNICAL STANDARDS. **NBR 15200**: Design of concrete structures in fire conditions. Rio de Janeiro: ABNT, 2012.

CAIXA ECONÔMICA FEDERAL. **SINAPI – National System for Research on Costs and Indices in Civil Construction**. [No place], [no date]. Available at: <https://www.caixa.gov.br/poder-publico/modernizacao-gestao/sinapi/Paginas/default.aspx> . Accessed on: Apr. 8, 2026.

CARVALHO, N. Road tunnels. In: CELESTINO, T. B.; KOSHIMA, A.; TELLES, R. C. A.; ASSIS, A. (eds.). **Tunnels of Brazil**. São Paulo: CBT/DBA, 2006. pp. 26–107.

DOMINGUES, Vinícius Resende. **Construction techniques for underpass tunnels**. 2016. 168 p. Thesis (Master's in Civil Engineering) – University of Brasília, Brasília, 2016.

FLORES, Joubert. São Paulo Metro, a national benchmark. **ANPTrilhos – National Association of Rail Passenger Transporters**, Brasília, Sept. 14, 2024. Available at: <https://anptrilhos.org.br/50-anos-do-metro-de-sao-paulo/> . Accessed on: Apr. 20, 2026.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. **ISO 31000:2018** – Risk management: guidelines. Geneva: ISO, 2018.

JOPPERT JUNIOR, Ivan. **Building foundations and retaining structures**: total quality in project management and execution. São Paulo: Pini, 2007. 220 p.

KUTNER, A. S.; BJORNBERG, A. J. S. Contribution to the geological-geotechnical knowledge of the São Paulo Basin: lithotypes, stratigraphic notation, and relevant structural features. **Revista Engenharia**, no. 522, pp. 66–73, 1997.

LI, Ming-Guang; CHEN, Jin-Jian; XU, An-Jun; XIA, Xiao-He; WANG, Jian-Hua. Case study of innovative top-down construction method with channel-type excavation. **Journal of Construction Engineering and Management**, vol. 140, no. 5, 2014.

MASSAD, Faíçal. **Open-cut excavations in tropical soils**: central-southern Brazil. São Paulo: Oficina de Textos, 2005.

MEIER, Ricardo. See the map of Metrô and CPTM stations in 2026 with Line 17 included. **Metrô CPTM**, São Paulo, Apr. 6, 2026. Available at: <https://www.metrocptm.com.br/veja-o-mapa-de-estacoes-do-metro-e-cptm/> . Accessed on: Apr. 20, 2026.

MINISTRY OF LABOR AND EMPLOYMENT. **NR-18**: Occupational safety and health in the construction industry. Brasília: MTE, 2022. Available at: <https://www.gov.br/trabalho-e-emprego/pt-br/aceso-a-informacao/participacao-social/conselhos-e-orgaos-colegiados/comissao-tripartite-partitaria-permanente/normas-regulamentadora/normas-regulamentadoras-vigentes/norma-regulamentadora-no-18-nr-18> . Accessed on: Apr. 23, 2026.

MINISTRY OF LABOR AND EMPLOYMENT. **NR-33**: Occupational Safety and Health in confined spaces. Brasília: MTE, 2022. (SEPRT Ordinance No. 1,690, dated June 15, 2022). Available at: <https://www.gov.br/trabalho-e-emprego/pt-br/aceso-a-informacao/participacao-social/conselhos-e-orgaos-colegiados/comissao-tripartite-partitaria-permanente/normas-regulamentadora/normas-regulamentadoras-vigentes/norma-regulamentadora-no-33-nr-33> . Accessed on: Apr. 20, 2026.

OU, C. Y.; LIAO, J. T.; LIN, H. D. Performance of diaphragm wall constructed using top-down method. **Journal of Geotechnical and Geoenvironmental Engineering**, ASCE, vol. 124, no. 9, pp. 798–808, 1998.

SHUTTERSTOCK. Mechanized open-cut trenching in an urban environment. [S. l.]: **Shutterstock**, 2024. 1 color photograph. Available at: <https://www.shutterstock.com/image-photo/yellow-excavator-jackhammer-machine-on-construction-2541938993> . Accessed on: Apr. 20, 2026. License acquired by the authors.