

Drainage Tunnel in São Bernardo do Campo: Excavation Challenges in an Urban Environment

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ABSTRACT: This paper discusses the challenges encountered during the construction of a drainage tunnel in the downtown area of São Bernardo do Campo, developed as part of the Drenar Project. The project, initiated in 2015, underwent a temporary suspension, and the tunnel excavation was completed in 2018. The excavation was carried out predominantly in sandy soils under high groundwater conditions, without the possibility of dewatering due to the presence of old buildings located in the historical center. To ensure tunnel stability and safety, various ground treatment methods were applied, including tubular forepiling and cast-in-place concrete columns used as rigid inclusions (CCPH columns) for the stabilization of the tunnel crown and face. In addition, continuous-bulb forepiling, vacuum-assisted horizontal drains (DHPs), and systematic drainage systems were employed. These treatments were adjusted progressively as the work advanced, ensuring proper overlap with the excavation zones, especially in sections with curved tunnel alignment. The tunnel, with a total length of 980 meters, was excavated from three working faces: the first from a main shaft, and two others from an auxiliary shaft that enabled simultaneous excavation in both directions. This paper presents the construction techniques adopted, the adaptations implemented throughout the process, and the engineering challenges overcome to achieve the successful completion of this drainage tunnel.

1 INTRODUCTION

The Drenar Project aimed to eliminate or reduce the recurring floods caused by short-duration intense rainfall events in the upper basin of the Ribeirão dos Meninos, located in the central region of São Bernardo do Campo (SP). In recent decades, such events have occurred almost annually due to a gradual change in the hydrological behaviour of the basin, characterized by a reduction in concentration times and an increase in soil impermeability resulting from urban densification.

The Ribeirão dos Meninos, whose course is canalized along Avenida Brigadeiro Faria Lima — an important urban artery of the municipality — received, between the Anchieta Highway and the Paço Municipal, contributions from the Rotary, Casagrande, das Palmeiras, Santa Terezinha, Saracantan, and Água Mineral streams, as well as several drainage galleries. This configuration caused the system to rapidly reach its maximum capacity during heavy rain events, resulting in frequent flooding, including in the area of the Paço Municipal and adjacent zones containing public facilities and critical buildings.

To definitively solve the flooding problems, the project included a hydraulic reinforcement of the Ribeirão dos Meninos along the stretch between Avenida Prestes Maia and the basin outlet, at the confluence with the Taióca Stream. This reinforcement comprised a hydraulic tunnel approximately 1,000 meters long and a reservoir with a storage capacity three times greater than the Pacaembu detention basin. The design provided for the construction of a by-pass tunnel parallel to the existing gallery, dimensioned to receive the entire flow that previously overloaded the channel. Consequently, the existing gallery — which had insufficient capacity — now functions as an auxiliary structure, absorbing only the excess flows during extreme flood events.

The construction of tunnels in densely urbanized areas proved to be a technically relevant solution for the city's drainage system. In the case of the Drenar Project, adopting a subterranean tunnel made it possible to execute a large-scale infrastructure work within a highly urbanized region without causing significant surface impacts, while preserving existing buildings and maintaining urban traffic, and ensuring safety for both workers and pedestrians throughout construction. This strategy was particularly appropriate in contexts such as São Bernardo do Campo, where the limited availability of free space and the presence of multiple utility interferences made conventional surface solutions unfeasible. Figure 1 presents the general map of the region.

The use of underground solutions for urban drainage and transport infrastructure has been widely discussed in the literature as an effective approach to minimize surface disruption and utility interference in densely populated areas (ITA-AITES, 2014; Sterling et al., 2012).

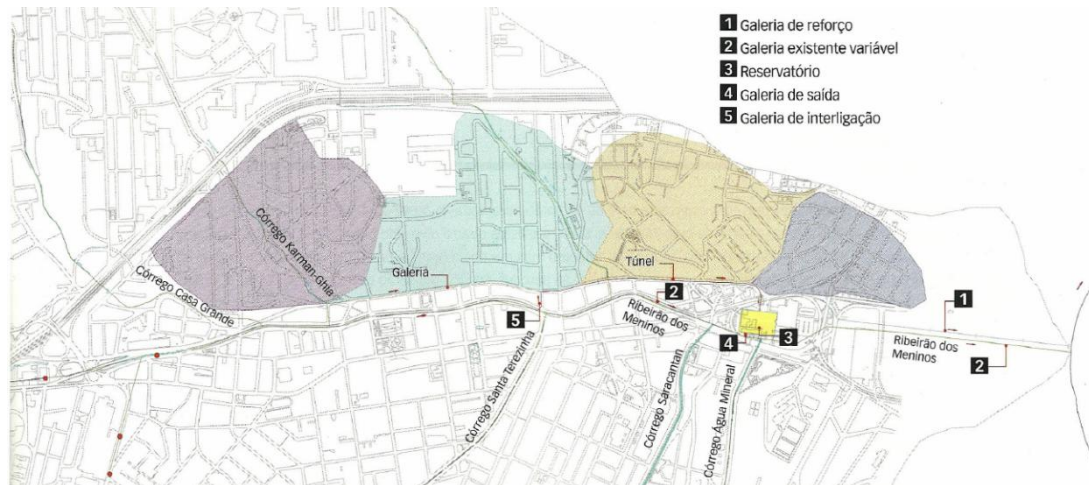


Figure 1. General map of the region.

The tunnel beneath Rua Jurubatuba was designed to collect stormwater from the Avenida Brigadeiro Faria Lima gallery and from contributing basins on the left bank, including the Córrego dos Lima and adjacent drainage galleries. The choice of a by-pass tunnel was justified by the high density of urban occupation, which made surface interventions impractical, and by the need to ensure continuity of local traffic during construction.

For the execution of the Main Tunnel, three complementary underground structures were constructed: Shaft 01, Shaft 02, and a Service Tunnel, which played essential roles in excavation operations, ventilation, and site access. Figures 2 and 3 show the general layout of the tunnel and the associated structures.

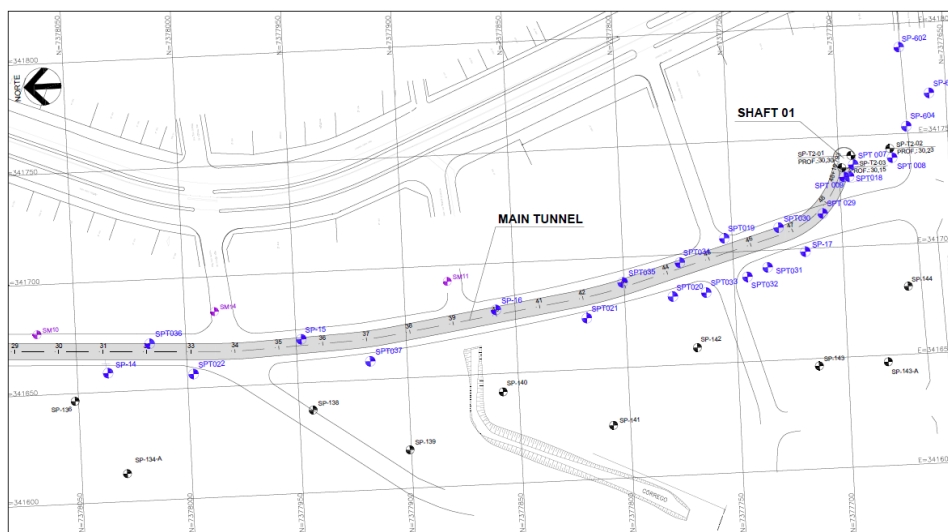


Figure 2. General map of the region. General layout of the tunnel – part 1. (Source: GeoCompany Executive Design).

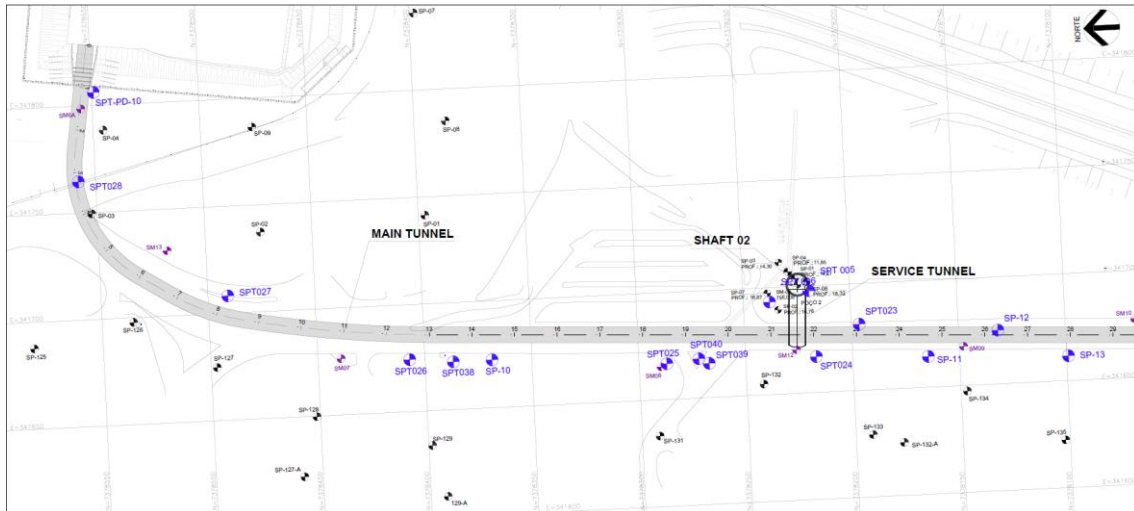


Figure 3. General map of the region. General layout of the tunnel – part 2. (Source: GeoCompany Executive Design).

2 LOCAL GEOLOGY

The area of the Main Tunnel is located in the central region of São Bernardo do Campo (SP), within a geological context characterized by the presence of recent deposits associated with the alluvial plain of the Ribeirão dos Meninos and by the crystalline basement of the São Roque Group. The geological profile identified along the tunnel alignment reveals the occurrence of three main units: technogenic deposits, alluvial deposits, and residual soils of metamorphic rocks, as described below.

The technogenic deposits are composed predominantly of construction and demolition materials (RCD), micaceous silty sand–clay soils, and heterogeneous portions of reworked soil. They present variable thickness, generally limited to the near-surface layers, and are associated with urban occupation and buried utilities along Avenida Brigadeiro Faria Lima and Rua Jurubatuba. This superficial layer is unstable and not suitable for direct excavation without prior ground treatment.

The underlying sequence consists of recent alluvial deposits, composed of soft to very soft organic clays, saturated loose sands, and silty sands, typically exhibiting high moisture content and low shear strength. These formations correspond to ancient meanders and paleochannels of the Ribeirão dos Meninos and its tributaries. The presence of compressible and saturated soils in this layer required special attention in the design of temporary structures and in the control of settlements and uplift pressures during the initial excavation phases and construction of the access shafts.

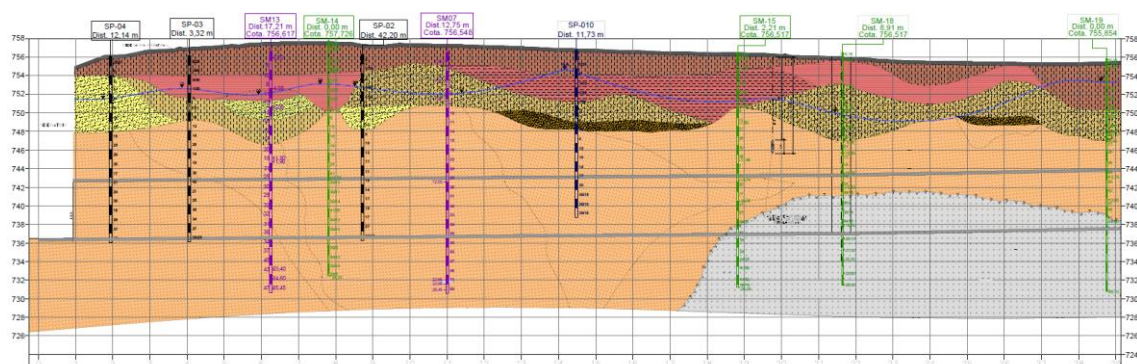


Figure 4. Geological profile of the tunnel – part 1. (Source: GeoCompany Executive Design).

Below these recent deposits occur the residual soils and rocks of the crystalline basement, composed mainly of mica schists and, subordinately, micaceous gneisses, belonging to the Embu Complex. These materials exhibit a variable degree of weathering, with a gradual transition from

saprolitic soil (saprolitic residual soil) to sound rock at greater depths. The more weathered zones display a foliated structure and a high content of micaceous minerals, which influence the anisotropic behaviour of the rock mass and require particular attention to the excavation direction and initial support system. The influence of weathering degree and anisotropy on excavation behaviour and support design is well documented in tunnelling practice (Hoek, 2007).

The Main Tunnel was excavated predominantly through weathered material derived from the crystalline basement rocks, with localized occurrences of sound rock at the tunnel invert, mainly between stations 20 and 36. This characterization was made possible by an extensive geotechnical drilling campaign carried out along the tunnel alignment, which allowed for the accurate definition of the geological profile and the optimization of the construction solutions.

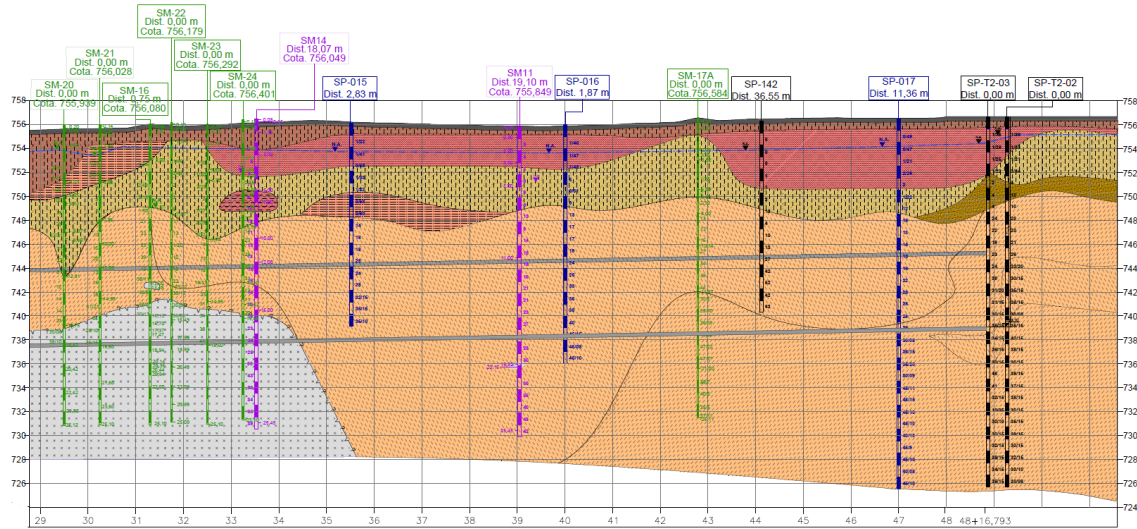


Figure 5. Geological profile of the tunnel – part 2. (Source: GeoCompany Executive Design).

3 IMPLEMENTATION

The Main Tunnel, with a total length of 961.77 meters, was designed to optimize excavation progress while minimizing impacts on the urban surface. To achieve this, three excavation faces were planned, initiated from two large-diameter service shafts, designated Shaft 01 (9.2m of diameter) and Shaft 02 (9.6m of diameter), strategically positioned along the tunnel alignment.

From Shaft 02, two simultaneous excavation faces were developed: one toward the reservoir located near the Paço Municipal, and another toward Shaft 01, allowing for convergent excavation and a significant reduction in overall construction time.

Shaft 01, in turn, housed the third excavation face, which advanced toward Shaft 02 until it met the approaching face from that direction. This strategy of working with multiple excavation fronts enabled the optimization of material removal logistics, improved control of local geotechnical conditions, and ensured schedule continuity, even under the spatial and traffic constraints inherent to the urban environment.

After completion of the excavations and the construction of the internal structures, the shafts were fully backfilled and subsequently sealed with reinforced concrete cover slabs, designed to restore the surface for vehicular traffic and reestablish the original circulation conditions. These structures do not perform any operational or hydraulic function in the final drainage system.

Through this approach, the project successfully achieved its functional and safety objectives with minimal interference to urban activities, both during and after construction.

A comprehensive geotechnical monitoring program was implemented throughout the tunnel excavation in accordance with NATM principles. Instrumentation sections were installed at 20-m intervals along the tunnel alignment and included surface and subsurface settlement markers (extensometers), convergence pins, and piezometers to monitor ground deformation and groundwater behaviour.

In addition, settlement markers were installed on buildings located within the tunnel influence zone to control potential excavation-induced movements. At the shafts, inclinometers were also installed to monitor lateral ground displacements. The monitoring data were systematically

evaluated during construction and used to support excavation control, ground support adjustments, and safety verification in the urban environment.

4 TUNNEL EXCAVATION

The excavation of the Main Tunnel was carried out through three working faces, starting from two large-diameter service shafts, designated Shaft 01 and Shaft 02.

From Shaft 02, two excavation faces were developed: one toward the reservoir located near the Paço Municipal, and another toward Shaft 01. The latter housed the third excavation face, which advanced until it met the approaching face from Shaft 02.

The excavated cross-section had an area of approximately 34.80 m². Excavation was performed under predominantly dry conditions, with localized drainage, at an average depth of 18 meters below the surface, measured to the tunnel invert.

The construction method adopted was the NATM (New Austrian Tunnelling Method), characterized by continuous observation of the rock mass behaviour and the use of a flexible, adaptive primary support system. This approach follows the principles originally proposed by Rabcewicz (1964) and later formalized through the observational method concept (Peck, 1969). The excavation was divided into three sequential stages:

1. Excavation of the top heading, corresponding to the upper third of the section;
2. Execution of a temporary invert arch, partially closing the section to ensure stabilization;
3. Construction of the final invert arch, completing the tunnel's primary lining.

Due to the proximity of sensitive surface structures and the urban characteristics of the alignment, the tunnel was excavated beneath one of the city's oldest streets, where several houses had foundations supported by timber piles. This condition required strict control of ground vibrations and deformations throughout the excavation process.

Plasma excavation technology was selectively applied along a 150-m-long section of the tunnel where excavation intercepted a rock mass beneath a vibration-sensitive urban area. The method was adopted as a controlled alternative to conventional blasting, due to the presence of surface buildings founded on timber piles and the need to strictly limit vibration levels.

Prior to its application, a vibration attenuation study based on elemental wave modeling was carried out to define the drilling pattern, charge configuration, and initiation sequence. Field tests and sismographic monitoring confirmed that the peak particle velocity (PPV) levels induced by plasma excavation remained well below the regulatory limits established by CETESB (Companhia Ambiental do Estado de São Paulo, the environmental protection agency of the State of São Paulo, Brazil), while providing adequate rock fragmentation. This approach ensured safe excavation through the rock mass with minimal impact on surface structures and surrounding urban activities.

To ensure the safety of surface structures and residents, a plasma excavation technology was employed, which made it possible to significantly reduce vibrations and dynamic impacts typically associated with conventional excavation methods, thereby maintaining the stability of existing foundations and preventing damage to nearby historic buildings.

Two types of crown treatment were adopted, depending on local geotechnical conditions:

In sandy subsoil, a systematic treatment using CCPH columns (Ø60 cm) was applied to increase cohesion and confinement in the excavation face; In clayey subsoil, tubular grouted forepiling (Ø10 cm) with SCH-40 steel pipes (Ø2½") was employed to provide adequate support and settlement control.

At the excavation face, whenever weaker ground or high saturation conditions were encountered, occasional treatment using continuous-bulb PVC forepiling was applied to ensure greater stability during advance.

To control groundwater pressure, localized dewatering was performed using deep horizontal drains (DHPs), operating both by gravity and under vacuum, according to the local flow and permeability conditions, four horizontal drains were installed per tunnel cross-section. The primary objective of this system was to locally reduce pore water pressure at the excavation face—particularly in sandy soil sections—thereby improving face stability and excavation safety without inducing regional groundwater drawdown.

Conventional groundwater lowering was not adopted in order to avoid excavation-induced settlements in the surrounding area, which corresponds to a densely occupied and historic urban

center. The presence of old buildings and sensitive foundations made any regional drawdown of the groundwater table unacceptable from a geotechnical risk perspective.

The primary lining consisted of reinforced shotcrete, with lattice girders in the crown and welded wire mesh in the invert, providing immediate strength and flexibility in accordance with the NATM principles.

The secondary lining consisted of plain shotcrete reinforced with welded wire mesh, without the use of steel fibers, providing increased stiffness and long-term durability to the final structure.

The figures below illustrate some of the main construction stages of the Main Tunnel, including excavation, ground support, drainage, and structural closure.



Figure 6. View of the excavation face showing (a) the CCPH columns and (b) the forepiling. (Source: GeoCompany Construction Supervision – ATO).



Figure 7. Reinforcement installation for final invert arch concreting and Excavation view showing the blasted rock mass. (Source: GeoCompany Executive Design).

The Service Tunnel, extending 24.44 meters from Shaft 02, was excavated under geological conditions similar to those of the Main Tunnel, also employing sequential excavation and shotcrete support, and played an essential role in ventilation, access, and material transport during construction.

5 SHAFTS

The service shafts were fundamental structures for the construction of the Main Tunnel, serving as access points for excavation, ventilation, and material removal. Two shafts were designed — Shaft 01 and Shaft 02 — both of large diameter and strategically located to enable simultaneous advancement of multiple excavation faces.

The excavations were carried out using the NATM method, with segmented excavation in successive sectors, in order to preserve the integrity of the ground mass and control deformations during deepening. This methodology allowed for safe execution even within a densely urbanized environment and under variable geotechnical conditions.

Containment and waterproofing of the shaft walls were ensured through the construction of secant columns using jet grouting technology, forming an impermeable perimeter that eliminated the need for generalized groundwater drawdown. This solution contributed to excavation stability and to the mitigation of potential settlements in nearby buildings.

The shafts reached depths of approximately 20 meters, intercepting both weathered residual soils from the crystalline basement and localized portions of rock mass, which required the application of different excavation and support techniques. Excavation was carried out in controlled stages, following NATM principles. Temporary ground support was subsequently installed using reinforced shotcrete and steel lattice ribs, which remained in place until the construction of the internal slabs and tunnel connection structures.

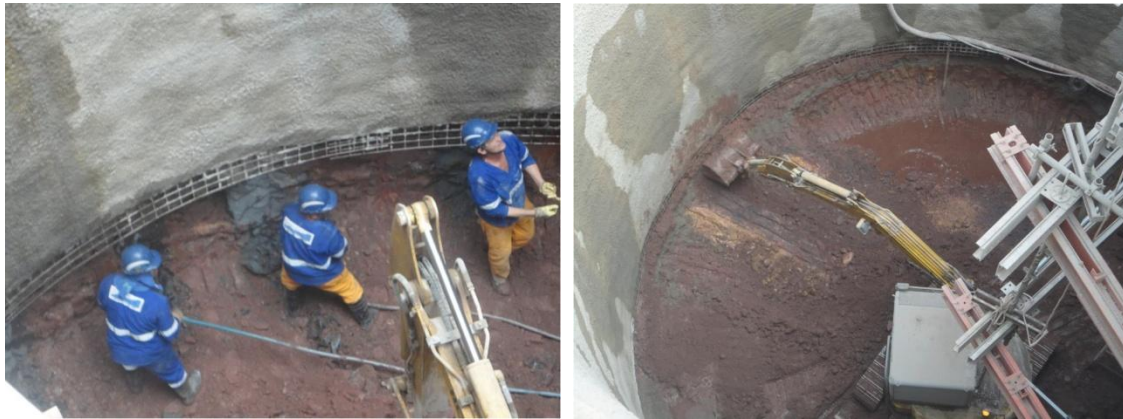


Figure 8. Detail of Shaft 1 showing (a) installation of the steel mesh reinforcement, where the discontinuity of the jet grouting columns can be observed, and (b) excavation in cohesive silty soil. (Source: ATO GeoCompany).

After completion of the excavations and the construction of the permanent structures, the shafts were sealed with reinforced concrete cover slabs, allowing the surface to be restored for urban traffic and the original site conditions to be reestablished.



Figure 9: Detail of Shaft 2 showing (a) beginning of water drainage and (b) excavation with pick hammer in a saprolitic residual soil section. (Source: ATO GeoCompany).

6 CONCLUSION

The construction of the Main Tunnel of the Drenar Project, in São Bernardo do Campo (SP), represents a significant milestone in urban engineering by combining complex geotechnical and construction solutions within a densely urbanized environment, overlying old and sensitive infrastructure. The project successfully achieved its primary objective of mitigating recurring flood events in the city's central area, contributing substantially to the improvement of the urban drainage system and to public safety.

From a technical perspective, the project was distinguished by the careful application of the NATM method, execution through multiple excavation fronts, and integration of complementary construction techniques to address highly variable geological and hydrogeological conditions. The use of secant jet grouting columns for the shaft walls enabled excavation without generalized groundwater lowering, thereby avoiding excavation-induced settlements in a densely occupied historic area.

In the tunnel, the adoption of differentiated crown treatments—CCPH columns in sandy soils and grouted tubular forepiling in clayey soils—proved effective in ensuring face stability and excavation safety. Groundwater control through systematic use of vacuum-assisted deep horizontal drains allowed local reduction of pore water pressure at the excavation face, particularly in sandy soils, without inducing regional drawdown, as recommended for urban tunnelling (Lunardi, 2008; Barla, 2016).

A particularly critical aspect of the project was the excavation beneath one of the city's oldest streets, where buildings were supported by timber pile foundations. In this context, plasma excavation technology was selectively applied in rock sections to replace conventional blasting. Vibration attenuation studies and field sismographic monitoring confirmed that peak particle velocity (PPV) levels remained within the regulatory limits established by CETESB, ensuring the protection of surface structures and sensitive foundations. Noise monitoring was not carried out, as excavation methods were selected primarily to control vibration levels and minimize urban impacts.

The project incorporated several technological innovations, including plasma-based controlled rock fragmentation in vibration-sensitive areas, vacuum-assisted horizontal drainage systems for localized groundwater control, and systematic geotechnical monitoring to support construction decisions in accordance with NATM principles. These innovations were fundamental to enabling safe excavation under stringent urban constraints.

The tunnel alignment crossed a densely occupied urban corridor with existing surface and subsurface utility networks, including drainage galleries and urban service lines. These constraints strongly influenced the selection of a subsurface tunnel solution, as open-cut alternatives would have required extensive utility relocations and caused severe disruption to traffic and urban activities. The adopted solution allowed construction to proceed while maintaining utility operation and minimizing surface interference.

From a sustainability perspective, the project contributed to urban resilience by reducing flood risks in a critical area, minimizing social and economic losses associated with recurrent flooding events, and limiting environmental and social impacts during construction. Underground construction avoided large-scale surface disruption, restricted groundwater drawdown, reduced utility relocations, and preserved existing urban infrastructure, reinforcing tunnel engineering as an effective and sustainable solution for urban drainage systems.

In summary, the Drenar Project Tunnel stands as a representative example of sustainable urban infrastructure, demonstrating how the integration of appropriate construction methods, technological innovation, and risk management can successfully address complex engineering challenges in densely urbanized environments.

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