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Examining 2007 São Paulo City Subway Line–4 Construction Site Accident

Analia Maria Andrade Pinto
Universidade Federal Fluminense, Brazil
analia.pinto@superig.com.br

Wainer da Silveira e Silva
Universidade Federal Fluminense, Brazil
wainer_uff@yahoo.com

Abstract

São Paulo is the largest city in Brazil and the most populous city in the Americas and the Southern Hemisphere. It is the fifth in the world by population. With extremely intense traffic, the city's 11 million people are served by a modern and continuously expanding subway network. The São Paulo subway is the largest in South America and considered to be one of the most advanced subways in the world. Constructing new subway lines and facilities in a very large city is not a simple task. Tracks must be built under residential and commercial buildings, crowded streets, and avenues, with minimal city life disruption. On January 12, 2007, a serious accident happened at the São Paulo metropolitan subway yellow line–4 construction site. As the wall of a concrete-lined shaft and the complete ceiling of the Pinheiros subway station collapsed without warning, it swallowed pedestrians, a minibus, and dump trucks on the site. The São Paulo subway is owned by the State of São Paulo. Companhia do Metropolitano de São Paulo is in charge of supervising a consortium of Brazilian civil engineering companies. The subway line–4 contract includes constructing a 12.8km concrete-lined tunnel, which is 9m in diameter. Line–4 will integrate the subway with both the suburban commuter rail system and the city's bus networks. Accidents can happen. However, this case renders some peculiarities due to the fact that fatalities involved no tunnel workers but only passing-by pedestrians and vehicle drivers or riders whose safety should have been carefully taken care. The objective of this paper is to examine the reasons for this accident so that we can both understand its peculiarities and try and make recommendations towards its avoidance in the future. We will use available data and official information, as well as interviews with construction and safety personnel.

Introduction

Cities all over the world are growing in size, population, and complexity. Therefore, transportation must be constantly improved. Mass transportation systems are often under continuous expansion. Among most mass transportation systems, subways have proven to

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be more advantageous due to their efficiency, convenience, and capability. Moreover, new subway lines do not affect other kinds of transportation, and they do not disrupt existing landscape, parks, or walkways.

Building subway lines is a typical procedure in large cities everywhere. While it is a good solution, it is not an easy one since the building of such subway routes is technically complex and expensive, demanding specific technology and management. The most evident civil engineering challenges include digging logistics and lowering the ground water. It is extremely hard to dig and turn useful large tunnels underneath the area of the future subway line surface with minimal disturbance. This is a difficult challenge for large cities in Brazil.

São Paulo is the largest city in Brazil and holds the largest population in the Americas, as well as in the Southern Hemisphere. With more than 11 million people in its urban center [1], São Paulo is served by a modern and efficient subway system that is continuously expanding [2]. Furthermore, the largest subway system in South America is building two new lines: the green line–2 and the yellow line–4.

The budget for this expansion work is approximately 8 billion U.S. dollars for the period from 2007 to 2010 [3]. Building these new subway lines has been contracted by the São Paulo state government through the state company, Companhia Metropolitana de São Paulo, which is in charge of contracting and supervising the subway expansion [4]. The work was assigned to CVA (Consórcio Via Amarela) a consort composed of five companies: Andrade Gutierrez, Camargo Correia, OAS, Queiroz Galvão, and Norberto Odebrecht. These are solid and large civil engineering companies with extensive experience in Brazil and abroad. They are building 12.8km of subway line, linking 11 new subway stations in an extremely dense population area.

Subway Construction Site Accidents

Due to the complexity and greatness of the work, accidents happen, regardless of both managerial concern and modern applied technology. Actually, three typical types of technologies for tunnel building have been used in São Paulo: NATM, VAC, and TBM. The first one, NATM (New Austrian Tunneling Method), refers to a kind of technology that uses explosives for digging before concreting and advancing. It was developed in Austria from 1957 to 1965. The second one, VAC (Vala de Céu Aberto or Cut-and-Cover), refers to a kind of technology where digging is used for opening large ditches, which are then bore up and covered later. Finally, the third one, TBM (Tunnel Boring Machine), refers to a kind of technology that uses a large machine that perforates, removes the rubbish, and bears up the walls.

When the accident happened January, 12, 2007, NATM technology was in use at São Paulo yellow line–4 subway extension.

Other accidents have happened in tunnel constructions using NATM technology due to the use of explosives. Having done research on tunnel building accidents using NATM technology during the past 25 years, the authors have found 41 registered accidents, and 10 of them are listed on Table 1. As can be seen, some of these accidents took place during the same project, such as the Munich, Germany, subway case in 1987. Another accident with fatalities happened during the same project in 1994. In 1994, the accident in the Heathrow Airport in London garnered media attention. It left several buildings damaged and one completely destroyed [5].

Despite the number of accidents using NATM technology, it does not mean it is worse than other technologies. According to Pelizza [6], collapse in tunnel constructions are not related to a specific technology; however, he states that NATM technology includes a high number of building sequential steps and, therefore, is extremely vulnerable to human execution mistakes or failures. A report published in 1996 details the safety conditions for NATM technology [7].

In this research we turn our attention to NATM technology because it is widely used in Brazil and was the technology used for yellow line–4 in São Paulo subway construction.

The São Paulo subway yellow line–4 accident damaged several nearby buildings, causing their owners to be evacuated. Those houses were repaired, and their owners were safely allowed to return to their homes. In addition, these owners have also been reimbursed for their individual economic loss.

The São Paulo accident attracted much media attention for causing the death of seven people. None of them had any relationship to the subway building work. In fact, one of them did work on the construction site; he was a truck driver. As the alarm sounded, he returned to his truck to get his personal documents. The accident happened at that exact moment, and his truck was completely buried.

The company material loss was not relevant, and none of the employees working in the tunnel were hurt because usual procedures were duly enforced, as we can see through several open interviews with people and experts directly or indirectly involved with the work. The other victims had no relation to the subway construction. They were passing-by pedestrians, vehicle drivers, and riders.

Main Causes for the Accident

The main causes of accident at the São Paulo subway extension yellow line–4 are related to the digging explosions on January 12. The engineers in charge of the digging on that part of the tunnel were informed that the planned explosion was done in a completely controlled way. It was a low intensity explosion, and it happened approximately 10 meters away from the exact site of the accident.

It is known that every explosion will generate vibrations that may cause rock or land movement, even if the specific explosion is under strict control. In an interview with Paulo Helene, a professor at the University of São Paulo and president of the Brazilian Concrete Institute, he stated,

> *Every explosion generates vibration which will loosen parts of the soil. But it is not possible to state whether that operation was or not correct, since we can not assure that the depressions were under projected standards and that all the calculations were really correct.*

The engineers say that depressions usually happen in this kind of work. They also assure that although the depressions were at a level that showed to be higher than where they had been on previous days, they were not so high as to call for an alert situation. Thus, they believed there was no reason to place the work under an alarm condition since the explosion was authorized. They stated that had the depressions been above the alert level, they would have cancelled the assigned explosion. Since the depressions were under acceptable levels, there was no reason to change the explosion procedures and schedule.

The Accident

Several engineers and workers who were in and around the workplace when the tunnel collapsed were interviewed. Most of them said it took approximately 10 minutes between the first relatively small falling down and the big collapse that tore off the ceiling of the Pinheiros subway station. Actually, it immediately opened a great crater that engulfed land, rocks, cars, trucks, and even a passing-by passenger van.

Approximately 10 minutes was enough time for the safety procedures to have allowed the workers inside the tunnel to safely evade the place. None of those workers were hurt in the accident. Thus, the accident consequences would not have been so tragic if it had not been for the extension of the accident to the outside area of the construction site.

When establishing the boundaries between the workplace and the urban area surrounding the construction site, companies may not extend the safety area as much to avoid disturbing the city life close to many streets and walkways. Therefore, Capri Street, which lies along the construction site, extending just around the work place, had not been closed. People and traffic continued to pass by the construction as usual. They were completely unaware of a possible accident that might jeopardize their lives.

During their interviews, engineers said that there would not have been enough time to close Capri Street. Surprisingly, during the interviews, there was not a single comment stating that somebody might even have mentioned trying any safety procedure aimed at warning people outside the construction site. We can assume that the project safety concerns were restricted to the construction site and to workers, as well as to any other construction involved personnel.

Could fatalities have been avoided? In reality, closing that street might have reduced those seven fatalities to just one fatality. Thus, it might have saved six lives.

According to the outstanding member of the IPT (Instituto de Pesquisas Tecnológicas, São Paulo) evaluation committee, Dr. André Assis [8], the final IPT report will soon be concluded. It will be translated into English and available for international researchers. This detailed report on the São Paulo subway construction accident will surely become an important source of knowledge for tunnel engineering worldwide, since it is expected to bring about many lessons learned from the accident.

TABLE 1:
Accidents Using NATM Technology in the Last 25 Years

YEAR	ACCIDENT LOCATION	COUNTRY
1984	Bochum Subway	Germany
1985	Bochum Subway	Germany
1986	Krieberg Tunnel	Germany
1987	Munick Subway	Germany
1994	Munick Subway	Germany
1996	Los Angeles Subway	United States
1997	São Paulo Subway	Brazil
1997	Carvalho Pinto Tunnel	Brazil
1999	H.Yorkshire Tunnel Heathrow Airport	United Kingdom

Avoiding Fatalities in Urban Area Tunnel Building Accidents

Accidents are not uncommon when building tunnels. During the last 25 years, NATM technology, although extremely efficient, has had a high history of accident occurrences.

Considering that constructing subway expansions in highly populated areas has often disturbed city life, which made people suffer, it is time to think about developing and enforcing special safety regulations that will bring benefits to all.

Indeed, when the São Paulo accident took place, all the safety regulations were effectively applied inside the construction site [9]. Nonetheless, people were killed. They were killed because there were no safety regulations concerning the surrounding area with its buildings and people, regardless of the fact of the building site was located in a highly populated urban area. Therefore, the authors firmly believe that a set of regulations concerning the surrounding area safety should be established and enforced at civil construction sites.

These regulations might even be concerned with the need for emergency communication systems that could detect an emergency situation and generate an alert for immediate closing of nearby streets and/or evacuate the surrounding areas to the building site. These procedures should be applied whenever the surrounding area is in danger due to the risk of imminent accidents.

If a system like this had existed and been enforced in the construction of São Paulo subway extension, the 10 minutes that allowed the evacuation of workers from inside the tunnel would have been enough for extending the alarm conditions to the surrounding area, potentially saving the lives of those people who died without having ever been aware of the existence of such risk in that area. Such unawareness of the risk eventually took the lives of those people.

Final Remarks

The authors hope that the view presented in this paper regarding the accident in São Paulo subway yellow line–4 will be useful to alert the authorities about the need for conducting a review on safety regulations and establishing new regulations, which will not only care for people directly involved with the construction, but will also increase safety for those living or passing by the work area.

References

[1] ROLNIK, Raquel, *São Paulo***.** São Paulo: Editora Folha, 2001.
[2] Scarinoella, Roberto S., "A Crise da Mobilidade Urbana em São Paulo." São Paulo em Perspectiva, Vol. 15, No. 1, SP, Jun/Mar 2001.
[3] Carvalho, Alessandra T; Silva, Wainer; Soares, Carlos, "Sistema Turn-key em Parcerias Publico Privadas: Linha 4 Amarela – Metrô de São Paulo." *Anais do Segundo Congresso Brasileiro de Gerenciamento de Projetos*. Salvador, Agosto de 2007.
[4] Ratificação, *Edital Concorrência Internacional No. 42325212 – Concessão para exploração de Transporte de passageiros da Linha 4 – Amarela do Metrôs de São Paulo*. Disponível em http://.azevedosette.com.br/ppp/projetos/estadual/aceso em jun 2007.
[5] HSE Report, *The Collapse of NATM Tunnels at Hearthrow Airport*. 2000.
[6] Pelizza, S. "Trends and Development in Tunneling." *Proceedings of the International Seminar on Urban Problems and Underground Solutions*. São Paulo, 1996 p. 1–24.
[7] HSE, *Safety of New Austrian Tunneling Method (NATM) Tunnels*. HSE Books, UK 1996.
[8] Assis, Sodré. "O Relatório IPT." *Editorial da Revista da Associação Brasileira de Mecânica dos Solos e Engenharia Geotécnica*. Edição No. 26, June 30, 2008.
[9] Companhia do Metropolitano de São Paulo, *Report on the São Paulo Metro Accident***,** São Paulo, 2007.

Biographies

ANALIA PINTO is a graduate student in the Civil Engineering Master's program at Federal Fluminense University (UFF).

WAINER S. SILVA has held the position of Dean of the College of Technology at Federal Fluminense University (UFF), in Rio de Janeiro, Brazil. He has been a Full Professor since 1988. He is also a Visiting Professor at Ohio University. Dr. Silva earned his Ph.D. from Vanderbilt University in the United States in 1983. He has published extensively in his field.