Simpósio Brasileiro de Mecânica das Rochas – SBMR 2016
Mecânica das Rochas e Engenharia de Rochas para Inovação e Desenvolvimento
Conferência Especializada ISRM 19-22 Outubro, Belo Horizonte, Minas Gerais, Brasil

NUMERICAL MODELLING AND DESIGN ISSUES OF MICROTUNNELS FOR URBAN MACRODRAINAGE - A CASE STUDY IN SANTA CATARINA, BRAZIL – COBRAMSEG 2016

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SUMMARY: Whereas the trends in construction of microtunnels suggest increasing usage of mechanized methods, in developing countries there are still some obstacles to their widespread usage – e.g. relatively high cost, lack of skilled manpower, shortage of equipment. In fact, manual methods are still the most prevalent practice in developing countries. This paper explores the role of numerical modelling to support the choice for hand digging over mechanized microtunneling solution in drainage projects. An important application of microtunnels relates to urban drainage projects. There is a pent-up demand for such projects, since urban flooding problems have become increasingly recurrent across the world. Particularly in Southern Brazil, one of the most critical and high risk flooding regions is the Itajai Valley, Santa Catarina State. In order to control or minimize the potential harm of floods, urban drainage or macrodrainage systems should provide underground infrastructures (tunnels, pipelines and conduits) to drain away floodwaters. This paper presents some analysis results using numerical models of microtunnels for macrodrainage, designed to reduce flooding risk in the Brusque municipality, Santa Catarina State, Brazil.

KEYWORDS: Microtunnels, macrodrainage.

1 INTRODUCTION

Today, in most big and mid-sized cities across the world, urban drainage projects are a top agenda item, with a pent-up demand for construction of microtunnels. Whereas the trends in construction of microtunnels suggest that mechanized methods might be increasing over the past two decades, especially in developing countries there are still some obstacles to their widespread usage – e.g. relatively high cost, lack of skilled manpower, shortage of equipment. In fact, manual methods are still the most prevalent practice in developing countries. This paper explores the role of numerical modelling to support the choice for hand digging over mechanized microtunneling solution in drainage projects.

The common definition of microtunneling is a trenchless construction method for installing pipes with remote-controlled equipment of arbitrary size (Iseley, 1997; ASCE, 2001; Salem, 2008) – although the diameter of most machines generally varies from 0.6 m to 2 m (Fig. 1a). In Europe, Japan and the USA this is the major construction method since the 80’s. Also, several studies point out that the microtunneling methods are becoming increasingly prevalent worldwide (Nicholas, 1998), especially in Southeast Asia, the Middle East and South America. However, despite the high demand, this is still not the case in most urban areas across Brazil.

In underground mining and tunneling large-scale projects there are alternative definitions for microtunnels based on the cross section dimensions rather than on the construction method. These alternative definitions tend to categorize as microtunnels the structures with span or diameter < 3 m (Guglielmetti, 2008). In brief, hand mined microtunnels define the basic scope of the projects herein presented.

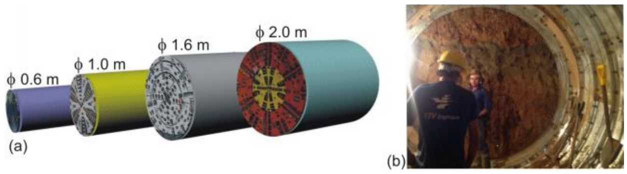

Figure 1. a) Microtunneling machines; b) hand digging.

The present study focused on an urban macrodrainage project in Southern Brazil with three microtunnels. Unjustifiably, in this project the choice for hand digging still prevailed over the mechanized microtunneling solution (Fig. 1b). This might indicate that the existing microtunneling technology is under-explored or not enough accessible/competitive in Brazil.

In recent years, the increased frequency of urban flooding events has raised the awareness of the central role played by trenchless methods and microtunnels in macrodrainage projects (Jha, 2012). This is a global issue that hits both developing and developed countries, as observed in the disaster in New Orleans (USA, 2005) and in the Elbe Floods (Germany, 2002). In Brazil, one of the major floods occurred in 2008 (Fig. 2) at the Itajai Valley, Santa Catarina (Fonseca, 2009; Fraga, 2012).

Figure 2. The worst climate disaster in Santa Catarina State.

After the 2008 flooding and a second major event in 2011, drainage projects became a top priority in this region (Braun, 2012). However, this urgent demand also revealed the lack of resources to support microtunneling methods. On the other hand, manual excavation was the most readily available (if not only) option. The next two sections will present in more detail the case study of three microtunnels in Brusque municipality, Santa Catarina State, Brazil.

2 BASIC CHARACTERISTICS OF THE PROJECT

The macrodrainage project for Brusque comprise several components, as open channels and drainage culverts, most based on traditional open trench methods. However, the project required trenchless methods. For the current implementation phase, the macrodrainage project includes 3 cross drainage culverts beneath a main road in Brusque (Table 1).

Table 1. Microtunnels (culverts) for the Brusque macrodrainage project.

Microtunnel	Diameter	Length
MT-01-BRUSQUE	2.80 m	81 m
MT-01-BRUSQUE	1.60 m	89 m
MT-01-BRUSQUE	2.60 m	177 m

The structural system of these microtunnels is based on the installation of corrugated steel liner plates (CSPI, 2007) and grouting injection to fill the voids between the plates and the soil.

In order to provide safety and load-bearing strength, both projects comprise other supporting means like vertical grout injection holes and a forepole umbrella (Fig. 3a). Also, the project recommends the usual monitoring practices based on continuous convergence and surface settlement measurements (Fig. 3b).

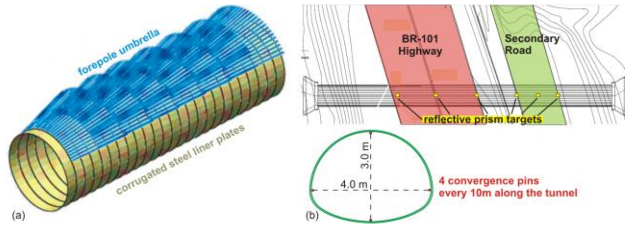

Figure 3. a) Auxiliary supporting means; b) convergence monitoring.

To compensate the lack of mechanized microtunneling methods, and to guarantee the safety and the rational use of resources, the design considered a thorough analysis of the sequential excavation using Finite Element Analysis. The mechanical performance of the proposed solutions was verified with 2-D and 3-D models with explicit representation of the supporting elements (steel plates, grout injection, forepole umbrella). The FE models also considered the soil non-linear mechanical properties (Mohr-Coulomb), determined from the soil investigation program (SPT).

3 STUDY CASE: BRUSQUE

The city of Brusque, located in the valley of the Itajai-Mirim river, was hit by severe floods in 2008 and 2011, leaving its downtown area completely submerged.

Besides other drainage components, the macrodrainage project for this region comprises 3 cross drainage culverts beneath a main road (Fig. 4).

Figure 5 depicts microtunnel MT-01-BRUSQUE, which has 81 m of length, 2.80 m of diameter and depth of 7 m beneath the main road.

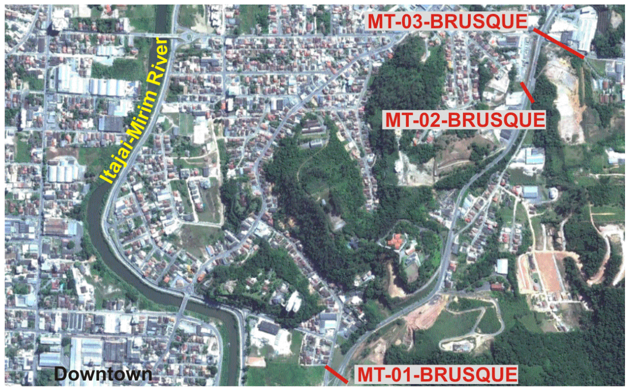

Figure 4. The 3 drainage microtunnels beneath a main road in Brusque.

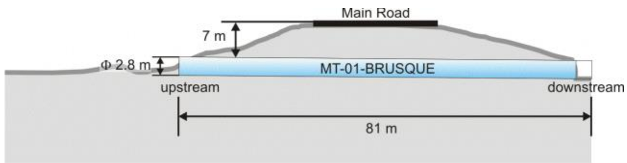

Figure 5. Microtunnel MT-01-BRUSQUE basic plan.

The numerical simulation with FE programs indicated an adequate level of safety in terms of the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS), both locally (liner plates, Fig. 6a) and globally (surrounding soil and the road, Fig. 6b).

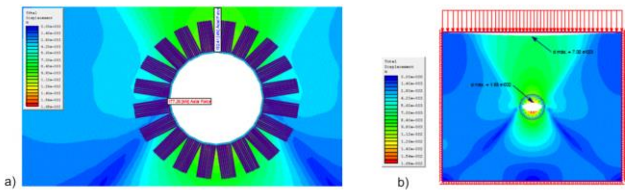

Figure 6. FE Analysis: a) stresses and axial forces – ULS; b) displacements – SLS.

Due to the weak soil conditions on both tunnel portals, the design specified a soil grouting through vertical injection pipes (Fig. 7). On the other hand, along the main body of the tunnel, due to the well-compacted and cohesive soil condition, the design recommended the use of a simply front support assembly and the injection of grout mortar to fill the voids between the liner plates and the soil.

Figure 7. Grouting through multiple vertical injection pipes.

Figure 8 depicts microtunnel MT-02-Brusque, which has 89 m of length, 1.60 m of diameter and depth of 11.50 m beneath the main road. This tunnel requires access shafts in both ends.

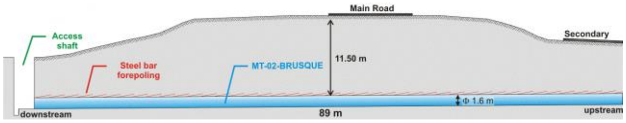

Figure 8. Microtunnel MT-02-BRUSQUE basic plan.

Due to its weaker soil condition, the design specified installation of short (2.50 m of length) steel bar forepoling over the crown of the tunnel with 30 bars of diameter 16 mm (Fig. 9).

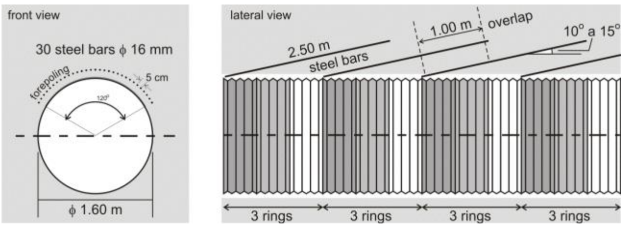

Figure 9. Steel bar forepoling for microtunnel MT-02-BRUSQUE.

Again, the numerical simulation with FE programs indicated an adequate level of safety in terms of the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS), both locally (liner plates, steel bars, Fig. 10a) and globally (surrounding soil and the road, Fig. 10b).

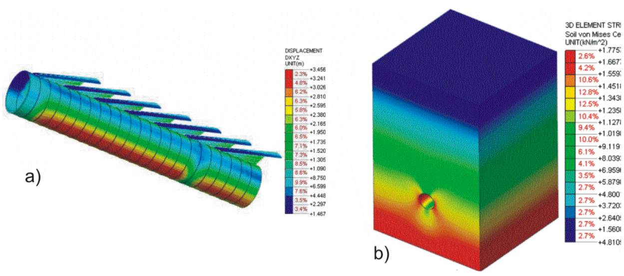

Figure 10. FE Analysis: a) stresses and axial forces – ULS; b) displacements – SLS.

Figure 11 shows the third microtunnel, MT-03-BRUSQUE, which has 177 m of length, 2.6 m of diameter and depth of 7.5 m beneath the main road. Basically, it required the same solution specified for microtunnel MT-02-BRUSQUE, with two access shafts and steel bar forepoling over the crown of the tunnel.

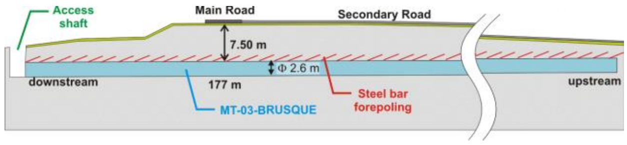

Figure 11. Microtunnel MT-03-BRUSQUE basic plan.

Similarly to the MT-02-BRUSQUE case, due to the weak soil condition, the design specified installation of short (2.50 m of length) steel bar forepoling over the crown of the tunnel but now with 50 bars of diameter 16 mm (Fig. 12a). Also, due to its larger cross sectional area, it recommended a partial face excavation (Fig. 12b), top heading (crown-bench).

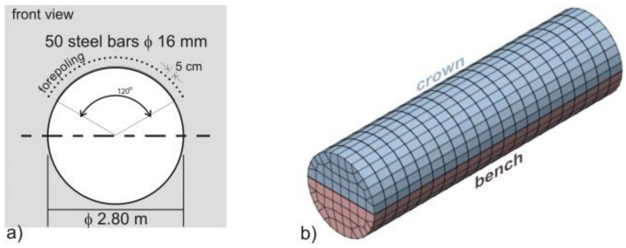

Figure 12. MT-03-BRUSQUE: a) steel bar forepoling; b) partial face excavation.

The FE simulation indicated an adequate level of safety in terms of the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS), both locally (liner plates, steel bars, Fig. 13a) and globally (surrounding soil and the road, Fig. 13b).

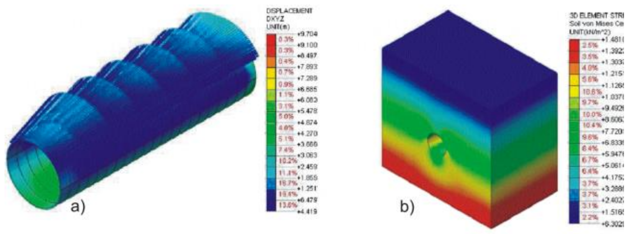

Figure 13. FE Analysis: a) stresses and axial forces – ULS; b) displacements – SLS.

4 CONCLUSION

The particular case of Santa Catarina State brings to the attention the lack of affordable microtunneling methods, despite the high demand for drainage projects using trenchless technology (NRC, 2013). The case studies presented herein demonstrate that hand mining still prevails over the mechanized approach in Brazil, indicating that the existing microtunneling technology is under-explored or not enough accessible or competitive. On the other hand, to counterbalance, the thorough FE analysis provided reliable and robust designs, compensating the lack of access to the more sophisticated methods of mechanized construction.

ACKNOWLEDGEMENTS

This work was supported by the Brazilian agency CNPQ (Grant number 561619/2010-7).

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