

Rio de Janeiro Metro – Vibrations due to blasting in urban environment.

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ABSTRACT: Rio de Janeiro Metro Line 1 is being connected to Line 4 and the excavations include several tunnels of different sizes, all of them excavated using drill and blast methodology. The vibrations due to blasting are continuously monitored, to control and, if necessary, adjust the blasting activities to levels compatible with the urban environment of Copacabana. The paper presents blasting data and associated vibration measurements, showing the relative compatibility with empirical correlations. Finally, some adjustments in the empirical coefficients are proposed.

1 INTRODUCTION

Several infrastructure projects are being carried out in the city of Rio de Janeiro for the 2014 World Cup and 2016 Olympics. Among them, the works for the expansion of General Osório station aims to optimize and to enhance the flexibility of the subway Line 1 operation, as well as to provide the job-site of the Line 4 construction with space for the installation and operation of the Tunnel Boring Machine (TBM).

The work is performed under the Cantagalo Hill, a rock mass that divides three southern neighborhoods of the city: Copacabana, Ipanema and Lagoa (see Figure 1).

The project includes the development of new ways for interconnection, parking decks, service areas and ventilation tunnels where more than 1800m of tunnels are being excavated with the drill and blast methodology.

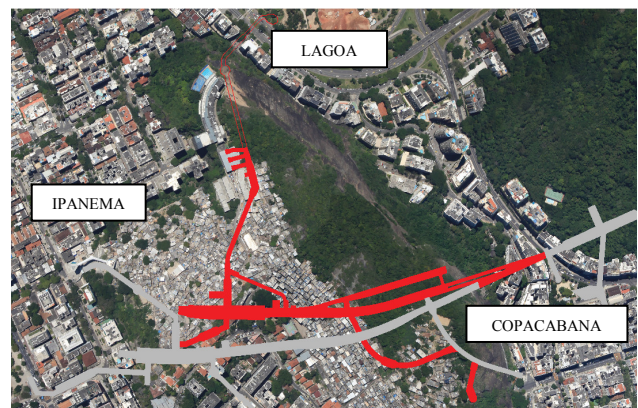


Figure 1. Situation Plan. In red the expansion of General Osório station.

2 CASE DESCRIPTION

The predominant geology of the rock mass shows a gneiss with a granitic composition (*Augen gneiss*) which sometimes is in contact with a sedimentary origin gneisses (*Kinzigite gneiss*). Both kinds of gneisses are divided by a fault zone with percolation of water. All this kind of rock was excavated by drill and blast method to ensure the development of low cost

and to have compliance with the construction schedule of the project.

The wide use of the drill and blast method in constructions around Brazil, provided the company with a "know how" that ensures the achievement of this kind of project in an urban area safely. However, the proximity of lines and stations, the presence of numerous residential buildings around the site and slums on top of the rock mass that is being excavated, implies a greater control of noise and vibration limits. Such control aims to ensure that the resulting vibrations generated by blasting do not exceed 50mm / s, as defined in standard (NBR9653) and the frequency lower than 40Hz, (because the natural resonance of the buildings lies below this value), and that the air overpressure does not exceed 134dbI, see Table 1.

Table 1. Velocity limits for peak particle vibration by frequency bands.

Frequency	Velocity limit for peak particle vibration
4Hz to 15Hz	Starting at 15mm/s, growing linearly to 20mm/s
15Hz to 40Hz	Over 20mm/s, growing linearly to 50mm/s
Over 40Hz	50mm/s

3 BLAST ISSUES

As previously mentioned, although a more effective method compared to other mechanized methods, the drill and blast has limitations due to environmental issues. This requires some exigencies on its management to attend the limits of standards.

Regarding to vibrations, some features may be used, such as, the strict control of the charge weights and their relative initiation times, reducing the drill depth, increasing the number of holes to improve explosive distribution and reduction of the contained load. The air overpressure in a tunnel is normally managed by adding blast doors and a good ventilation system.

Another important point that should be well managed is the use of primers. Conventional pyrotechnic initiation systems have a limited delay numbers causing multiple blastholes fire on the same delay. Sometimes this can be result

in a delay scatter in relation that was design for the excavation. This fact generates the sum of vibration waves which propagate along the rock mass, increasing the values of vibration and frequency. The detonating cords that are used with conventional primer should be well dimensioned because the overuse attenuates the shock waves from the blast.

4 TECHNICAL SOLUTION

Before starting the detonations, the vibrations parameters were established by determining an equation of the dynamic behavior of the rock mass.

The following equation represents this behavior:

$$PPV = K(R/W^\beta)^\alpha, \quad (1)$$

where PPV is the peak particle velocity (mm/s), R is the distance from the blast (m), W is the maximum instantaneous charge (Kg) and K , α and β are site constants.

For this study, the empirical values were used based in Li & Ng (1992) and Müller at all (2007). Based on these authors, the blasting data and associated vibration measurements were analyzed in order to show the relative compatibility with empirical correlations (see Figure 2 and Figure 3).

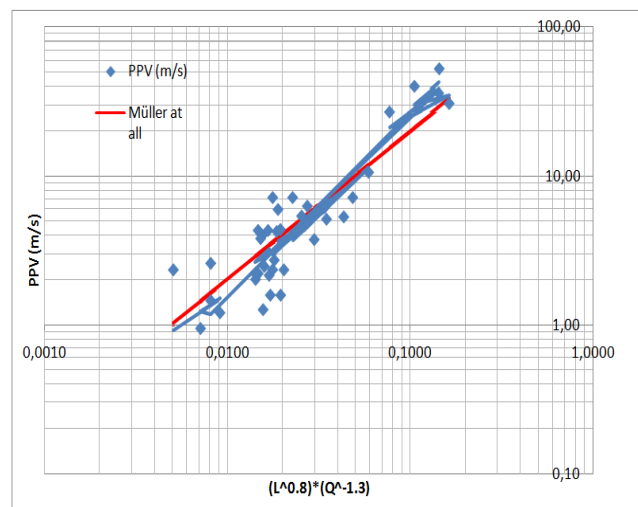


Figure 2. Graphical analyze using the parameters of Muller (red line) and the proposed coefficients (blue line).

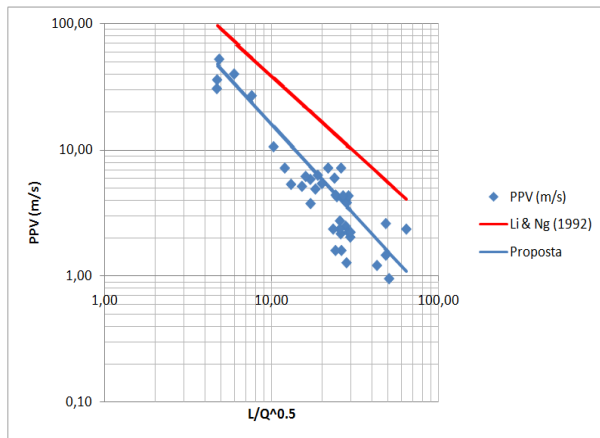


Figure 3. Graphical analyze using the parameters of Li & Ng (red line) and the proposed coefficients (blue line).

Finally, some adjustments on the empirical coefficients were proposed with the aim to better adjust the characteristics of the rock mass, see Table 2.

Table 2. Comparison between the empirical coefficients.

Parameter	Li & Ng	Muller <i>et al</i>	Proposed
K	644	206	450
β	0,5	0,8	0,5
α	1,22	1,3	1,45

Later the blast design was carried out for each section to be excavated. As the work consisted of several tunnels with different sections, the blast design has ranged from pilot tunnel 2m x 2m to step-by-step sections within five steps in order to prevent potential extrapolations beyond the limits of the standards besides attending the geological conditions.

As long as the sections were excavated, some adjustments in the blast design were necessary. The tools used for identification and improvement of blast design were basically the seismographs, the control chart for the detonations and the electronic initiation system.

4.1 Seismographs

Four seismographs that were deployed in order to accomplish the demands of a work in the midst of dense populated urban area were used. Three seismographs were required to be placed: one at the closest structure of the blast face, a second on the existing metro structures ranging

station and route operation and a third in the work environment. They analyze the vibrations as the blast face approached new structures or checking vibrations reported by the community that were complemented by technical surveys (see Figure 4).

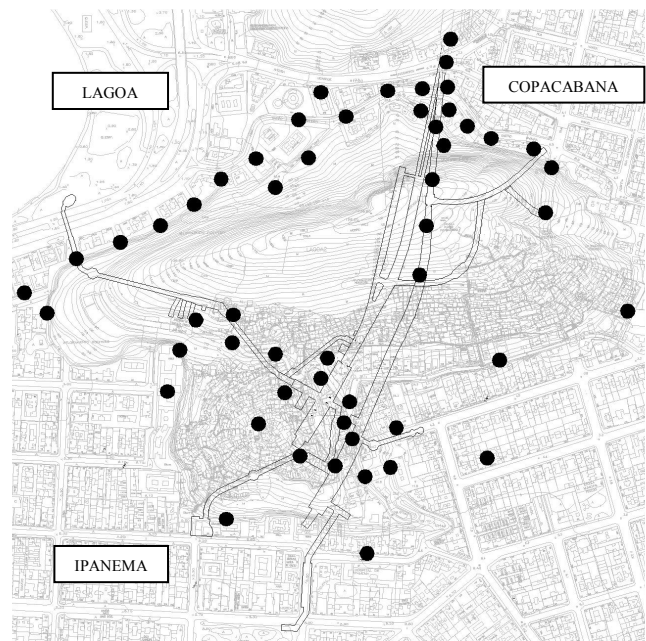


Figure 4. Seismography Plan.

4.2 Control chart for the detonations

The service control chart (FVS) is a document that contains the main information about the blast design which can be informed and detailed and then loaded. It registers the blast and potential changes occurring, in order to accomplish the demands of the work. In the ends of the blast process, it was possible to know all changes and settings of the face blast.

4.3 Electronic initiation system

The use of electronic fuses instead of pyrotechnic fuse is another important factor that contributed to reduce both vibrations and increase productivity (Kay and Song, 2005). The advantages of this type of fuse are due to trustworthiness on the delays, which present dispersion of about $\pm 0.1\%$ delay time programmed. This characteristic allows to ensure that each delay will effectively programmed to be detonated at the right time. As a comparison, pyrotechnic fuses feature a dispersion of $\pm 5\%$, causing the undesirable effects above mentioned. Furthermore, for the amount of delays, it was possible to adjust the

blast design for a lower expected maximum charge weight per delay, decreasing the vibration, improving energy dissipation and enabling greater advances. Although having a longer load time, (each individual fuse must be programmed separately before detonation), this time is compensated by a larger volume of blasting. Moreover, the system allows to identify the problems in the prior detonation fuse, preventing hot flashes because of a blast failure process.

5 CONCLUSION

The proposed guidelines have demonstrated excellent results through the practical application of methodologies and procedures, having a positive effect in reducing environmental risks.

The use of seismographs was effective in order to understand the vibrations of the rock mass and the structures, as well as the FVS favored the control and logistics of explosives. When analyzed together, that contributed to the improvement the blast design and showed that the use of electronic fuses allowed the work to be performed within the safety standards required.

At the end of the project, no structures of the surroundings suffered any damages related to the vibrations and the use of blast doors proved to be effective reducing the air overpressure.

Therefore, the success of the technical solutions used contributed to the continuous improvement of the company regarding urban construction and the management of the use of explosives for the environmental risks involved.

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