Design of controlled rock blasting for tunneling and tunnel portals

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ABSTRACT: Today there is a high demand for transport tunnels in Brazil, where the lack of logistical infrastructure is highlighted by the crowding of vehicles on highways and the congestion of trains on existing networks. The solution is overcoming the topographical relief complexities in urban centers and railway networks. This article deals with one of the tools for solving these problems: the fire plan for controlled rock blasting when opening tunnels and their portals, especially when the work of art is built under restricted conditions; geographic location, rock mass structural and mechanical characteristics, stress states arising from depth or induction from previously existing structures, interference with other transport routes, etc. in addition to all aspects inherent to blasting, such as vibration propagation, explosive force, and other parameters to be considered in its application. It should be noted, in this dimensioning, the use, among others, of the Line Drilling technique.

Keywords: Tunnel, Rock blasting, Line Drilling, Tunnel portal.

1 INTRODUCTION

The big problem with the use of explosives in rock blasting in urban areas is due to the phenomenon of vibrations caused by explosives, and they are the same ones that cause the rocks to rupture and their simultaneous fragmentation. To avoid any structural damage to neighboring buildings, depending on the values of velocity and frequency of particle vibration achieved, or the occurrence of unwanted overbreak of the rock itself, it is imperative to exercise care in the blasting.

For rock cuts in tunnels, roads, and railways, it is of greater importance that the remaining rock is of high quality to minimize block falls, rock failure, or excessive maintenance work.

To determine a blast design that does not produce undesirable effects on the environment, one must know, therefore, the characteristics of the explosives used, the structural characteristics and mechanical properties of rock masses, the state of active stresses, the speeds of vibration of material particles around them and the frequencies with which such vibrations occur. All these data can be obtained by monitoring, field surveys, and performing representative experimental tests and blasts that are well-planned and executed.

Internationally, literature is vast in this regard (Jimeno et al., 1995; Langefors & Kihlström, 1973; Lusk & Worsey, 2011; Mandal & Singh, 2009; A.T. Spathis & Gupta, 2012) although often not disseminated sufficiently in Brazil, but objective even of sufficient guidelines elaborated and published by the Brazilian Association of Technical (ABNT) (ABNT, 2018).

Safety limitations (of people and structures) and the prevention of discomfort conditions for the inhabitants of the vicinity of rock blasting work in urban regions should always guide the blast design methods to be proposed and employed. The project developed and presented here aims to exemplify a rock controlled blast design at the opening of tunnels and their portals, especially when the work of art should be built under restricted and challenging conditions in terms of geographical location, structural characteristics, and mechanical properties of the rock mass in which it is being performed, states of stress resulting from depth or induction by the relative proximity of other existing structures previously, interference with other transportation roads, etc. in addition to all the other usual aspects related to the characteristics of rock blasting, such as vibration propagation, explosive strength, and other parameters to be considered in their application. The technique that was most prominent in the sizing of the blast design was Line Drilling, a method developed for a long time for rock cutting (Jimeno et al., 1995) which is still relatively little used by Brazilian engineers, despite its excellent results in various applications.

2 CONTROLLED ROCK BLASTING

From the beginning of the explosives era in mining and in the construction industry, many efforts have been made to find control methods for overbreaking and remaining rock damages, with the development of special rock blasting techniques. All aim to minimize stresses and rock fracturing beyond the theoretical excavation line by reducing and/or better distribution of explosive charges. Initially, most of the methods used were by trial and error, but lately more scientific and sophisticated methods have been applied mainly in the United States and Europe (Mandal & Singh, 2009; A.T. Spathis & Gupta, 2012).

It is often stated that sound overbreak control cannot be expected in all geological formations. This is true, but carefully conducted rock blasting will minimize these effects even under unfavorable geological conditions.

The first attempt to control the overbreak was Line Drilling, which is simply a singular line of uncharged holes with very small spacing by following the perimeter of an excavation, ensuring the formation of a weakness plan according to which blasting should occur (Jimeno et al., 1995). Line Drilling has been modified over the years, with all or just a few holes being charged with light explosives charges. Additionally, the spacing between the holes was modified and increased.

New methods, such as Cushion blasting and Buffer blasting, were created and perimeter holes were detonated after the main fire (Jimeno et al., 1995).

The idea of delimiting (by cutting) the area to be blasted from the rock mass, creating a fracture throughout the theoretical blasting plan (perimeter), led to the development of pre-splitting blasting, where the holes of the perimeter are detonated before the rest of the fire (Jimeno et al., 1995). The above methods have applications in both surface and underground blasting applications.

The following observation is pertinent to the four methods cited regarding explosive charge calculations: in these determinations not only perimeter holes should be considered, but also the holes closer to the contour line (perimeter) should be charged in such a way that do not produce fractures that exceed the intended blasting perimeter.

2.1 Line Drilling

The idea that marks Line Drilling is to create a plan of weakness by drilling a line of holes, **without explosive charge**, with a small diameter and a very small spacing between them, along the perimeter of the excavation, surrounding the region that is being blasted and which is intended to isolate (main blasting). The creation of this cut, therefore, **will occur by the concentration of tensile stresses between the lines of the Line Drilling line**, caused by the propagation and impact of the front of the shock wave produced by detonation near the main blastholes, focusing on the line of empty holes (Figure 1 and Figure 4).

One of the main advantages of the technique is **to be applicable even when light charges can cause damage beyond the excavation line**. Among its disadvantages, the high drilling costs can be cited due to the small spacing between holes, the significant consumption of time due to extensive drilling, any minor diversions in drilling that can produce bad results, and the result of cutting quality that is directly proportional to the rocks' homogeneity. It is observed that the nearest (adjacent) mine holes of the line of Line Drilling are usually smaller than the rest of the blastholes. They are also charged with a smaller amount of explosive (lighter charge). Common practice is to reduce removal and spacing by 25% to 50% and reduce the charge by approximately 50% (see Figure 1). The charges should be well distributed along the hole attached to the igniter cord all its length. The best results are obtained in homogeneous rock formations, with a minimum of joints, plans of discontinuities, or altered layers (Jimeno et al., 1995). In fractured rock formations, Buffer blasting and Pre-splitting usually give better results (Jimeno et al., 1995).

The diameters of the line holes are usually less than 75 mm (3") and the spacing is 2 to 4 times the hole diameter. Using larger diameter holes is almost always very expensive.

For good results, precision in drilling is very important. Any deviation will produce harmful effects on the result.

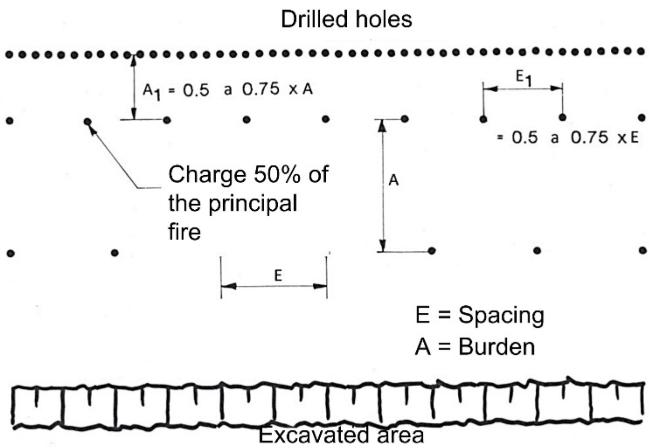

Figure 1. Upper view scheme for illustration of the Line Drilling technique - Source: authors.

2.2 *Seismographic monitoring*

Seismography is very important in urban areas and close to buildings in general to control the vibration produced by the detonation of explosives.

These values are evaluated through an indicator provided by the normative guidelines available as a limit.

In Brazil, "ABNT NBR 9653 /2018 - *Guia para avaliação dos efeitos provocados pelo uso de explosivos nas minerações em áreas urbanas*", is specific to evaluate the effects caused by using explosives on mining in urban areas (ABNT, 2018).

The standard specifies the maximum particle vibration velocity (peak velocity) admitted, in mm/s, of the longitudinal, transverse, or vertical components of peak speeds. These speeds are also considered as a vibration frequency function.

For low frequencies (from 4 to 15 Hz) the maximum recommended vibration speed varies in the range of 15 mm/s to 20 mm/s. For frequencies greater than 40 Hz, one can work at a top speed of 50 mm/s (see Figure 2).

In addition, the acoustic pressure (measured beyond the operating area) must not exceed 134 dBL. Flyrock (if any) should not occur beyond the work operation area.

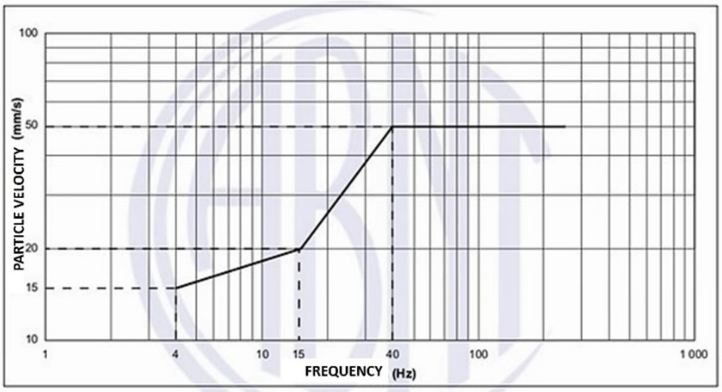

Figure 2. ABNT - NBR 9653 / 2018 - Source: ABNT.

3 BLAST DESIGN PROJECT

For reasons of confidentiality, the exact location of this engineering work, as well as several companies involved in the various phases of the railway tunnel project, will not be cited. One sought to illustrate the blast design project for opening the tunnel and its particularities in the face of the challenges found.

It is important to note that it was a work of great relevance to the Brazilian rail system, seeking to solve an important operational bottleneck in the flow of the production of agricultural goods and fuel to the port terminals of the country's southeast. Duplicating a specific stretch of the rail network, the number of load trains between the countryside and the Brazilian coast was considerably widened.

Likewise, it was very complex and logistically difficult work, as the tunnel to be opened over 100 m long, an excavation section of approximately 9.4m high and 8.1m wide, was found under one of the busiest highways of the country's Southeast. Due to the importance of this highway of intense traffic in the national context, the occurrence of long stoppages or traffic deviations was not possible.

3.1 Structural characteristics, mechanical properties of rock mass, excavation method

Other challenges that were considered in the development of the blast design project were the low coverage stretches (reaching almost 1 m), the proximity of the excavation with the existing rail tunnel on the side, and the freeway at the top.

The geological geotechnical profile was obtained through exploration drillings (see Figure 3). The rock mass presents a surface layer of sandy silt with varied penetration rates of 8 to 40 blows. At a greater depth is a fractured granitic rock, being projected in it the tunnel's excavation by the New Austrian Tunneling Method (NATM) method.

As is well known, NATM basically consists of carrying out excavations by controlling the rock mass deformations, in such a manner that it contributes to the support of the excavated tunnel, so that stresses are distributed and absorbed. In order to avoid spaces that lead to the accommodation of the rock mass, the tunnel is commonly excavated in an oval shape and shotcrete is projected immediately after excavations (Karakuş & Fowell, 2004; Leite & Lapolli, 2015).

The thickness determined for the tunnel lining was 26 centimeters of shotcrete. The characteristic strength of the ideal compression of this concrete was calculated at 250 kgf/cm^2 (25 MPa). The concrete, according to the project, should be armed with 2 layers of CA-60B electro-welded steel screens and a 4 cm armor covering (Leite & Lapolli, 2015).

Due to the low thickness of soil coverage and the impossibility of stopping the highway for long periods, it was essential to ensure the total stability of the vault and the excavation face. For this, it was stipulated the use of tubular pipe umbrella systems composed of 2 ½" Sch-80 steel tubes in diameter, equally spaced of 40 cm inserted in 4" diameter holes. And for the fixation of the tubes, low-pressure cement injection was designated to avoid damage to the highway floor (Leite & Lapolli, 2015).

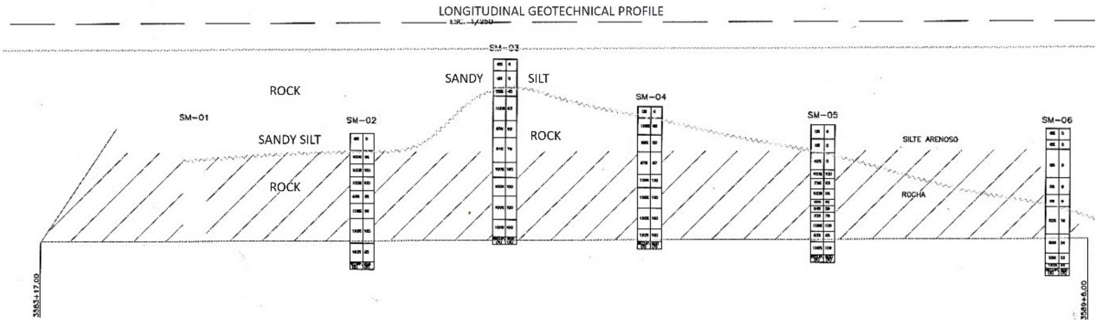

Figure 3. Geological-geotechnical profile - Source: (Leite & Lapolli, 2015).

3.2 External blast design –portal

In soft materials, such as soil and saprolite, excavation was mechanical with the use of manual breakers, excavators, and loaders. The work was carried out through 2 faces, being started in the north portal and, later, by the south portal. The larger volume of rock (Figure 3 and Figure 4) was blasted with the use of explosives and there was a greater application of the Line Drilling technique. These explosives were carefully applied following the elaborate and strictly controlled blast design, so that there was no risk to the workers and adjacent structures, such as the **existing tunnel on the side (which remained operating throughout the excavation) and the highway at the top. Overbreak was also avoided and there was no launch of rock fragments in the railway of the existing line.**

Despite the detailed study carried out before the start of the work, it is observed that daily follow-up, with each advance, is fundamental, enabling the description and confirmation of the geological-geotechnical conditions of the rock mass to readjust, if necessary, any relevant parameter, in the proposed blast design.

Among the parameters verified for the classification of the rock mass's quality, the description of the material found at each advance, the conditions of the fractures and their directions (favorable or not to the work), and the verification of the existence or not of water can be cited.

It is observed that the advancement by the southern portal was smaller, due to a late start or material of lower quality, requiring greater care in the excavations. It is also important to emphasize that the main blast design studies were made for the development of the external level in the north portal, where the material to be blasted was in surface, very close to the existing railroad (Figure 4).

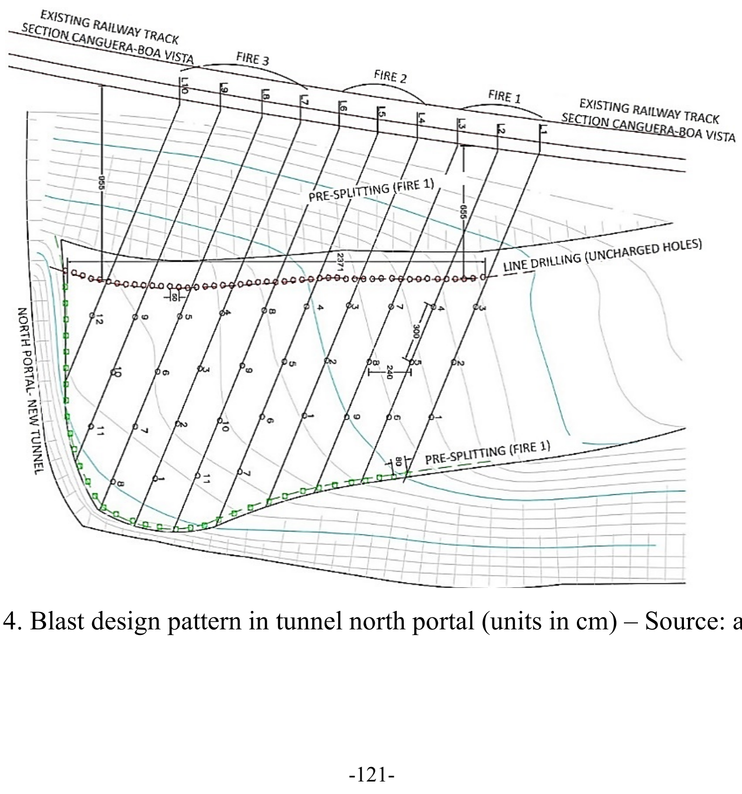

Figure 4. Blast design pattern in tunnel north portal (units in cm) – Source: authors.

It should be noted that all blasting operations had constant and rigorous seismographic monitoring.

Even with the presence of a fractured rock mass, there was the occurrence of a cut due to the emergence of traction stresses in the union of empty holes. This condition produced large-diameter blocks that remained on site as a protective wall, avoiding the launch on the adjacent railway (see Figure 5c).

The sequence of fires indicated in Figure 4 refers to the cut of the final level in rock that leads to the northern portal and at the same time triggers the activation of the Line Drilling that produces the existing rail isolation (see Figure 5 - Sequence).

Figure 5. Photos of the portal execution steps in the specific tunnel – Source: authors.

4 CONCLUSION

In short, it is conclusively evident in this work that the techniques adopted, and the blast design project used have been able to achieve the intended objectives in terms of safety, working conditions, external interference by vehicle circulation, and stresses control conditions and vibrations that could have had various harmful effects, including on the other juxtaposed and much older underground tunnel.

The projects developed here also demonstrate that blasting by explosives can be used safely and efficiently, observing the safe distances between the fires performed and the targets to be protected.

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