Iso-velocity maps. A vibration control tool in quarries

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Abstract

Urban growth around mining areas has brought problems such as neighborhood's discomfort due to blasting vibrations, which can cause structural damage to the houses, dust and atmospheric overpressure. In Brazil, environmental restrictions are increasingly rigorous and seismic monitoring is required as an environmental control measure. This study aims to analyze a methodology for application of iso-velocity maps in quarries located in urban areas and evaluate options for building iso-velocity maps. This work was performed in a quarry located in the State of São Paulo and four blastings were monitored. All blastings had similar features and they were evaluated in the same bench. For each equation, directional, scaled-distance parameters were estimated and different iso-velocity maps were made and compared. It is concluded that geophone disposition must adjust to the monitoring purposes. Eight to fifteen aligned geophones are adequate for a scaled-distance curve. Sixty-four or more geophones, spatially and homogeneously distributed, can generate an iso-velocity map concerning a single blasting. High variability of rock mass features seems to prevent obtaining good results when the seismographs are not homogeneously distributed surrounding the blasting.

Keywords: Iso-velocity map, environmental control, scaled-distance equations, ground vibrations, seismic monitoring.

1. Introduction

In the past, mining areas were generally located far from urban conglomerations. However, over the years the occupation of new locations has been required, resulting in daily coexistence between city inhabitants and the mining area.

Urban growth around mining areas has led to new problems due to discomfort that may be caused to the neighborhood and structural damage resulting from propagation of terrain vibrations, atmospheric overpressure and fly rocks. Dispersion of particulate matter may also occur (Bacci *et al*., 2006).

There are regulations limiting vibration and noise levels in order to protect the neighborhood and such environmental restrictions are becoming more rigorous (Bacci *et al*., 2003). Seismic monitoring is increasingly required to aid in legal disputes between mining companies and the population. In this context, seismic monitoring aims to improve blasting performance regarding costs and productivity, as well as to help attenuate environmental effects and reduce social conflicts.

Geosonics Inc. (Rudenko, 1998; Froedge, 1990 and Froedge *et al*, 1994) was the first company to use the methodology of iso-velocity maps. More than a hundred of triaxial sensors may be positioned around a blasting site and the effect of an explosive charge is tracked as the vibration wave moves away from the site. Iramina (2002) developed a hybrid method with eight scaled-distance equations simulating an iso-velocity map.

Multidirectional trends of vibrations propagation related to a single blasting can be detected using the iso-velocity map (Khaled *et al*., 2007). It compares favorably with measurements using only one or two seismographs, which is the usual practice in most quarries and mining areas in Brazilian urban areas.

This study aims to analyze a methodology for application of iso-velocity maps in quarries located in urban areas and evaluate options for building iso-velocity maps.

2. Materials and methods

In this study, four blastings were monitored, each one of them with four different directions selected, using a total of 20 SSU 3000EZ+ and SSU 3000LC seismographs. All blastings were evaluated in the same bench, presenting similar blasting plans. For each equation, the directional, scaled-distance parameters were estimated and different iso-velocity maps were generated and compared.

The seismographs were set for

activation at a lower sensitivity limit (trigger) between 0.18 and 5 mm/s depending on the proximity to the blasting site and considering the possibility of activation by any other event, like a passing truck. Record time was set between 5 and 7 seconds, according to ISEE's recommendations (2009).

The blasting distribution in the bench and the location of monitored points are presented in Figure 1.

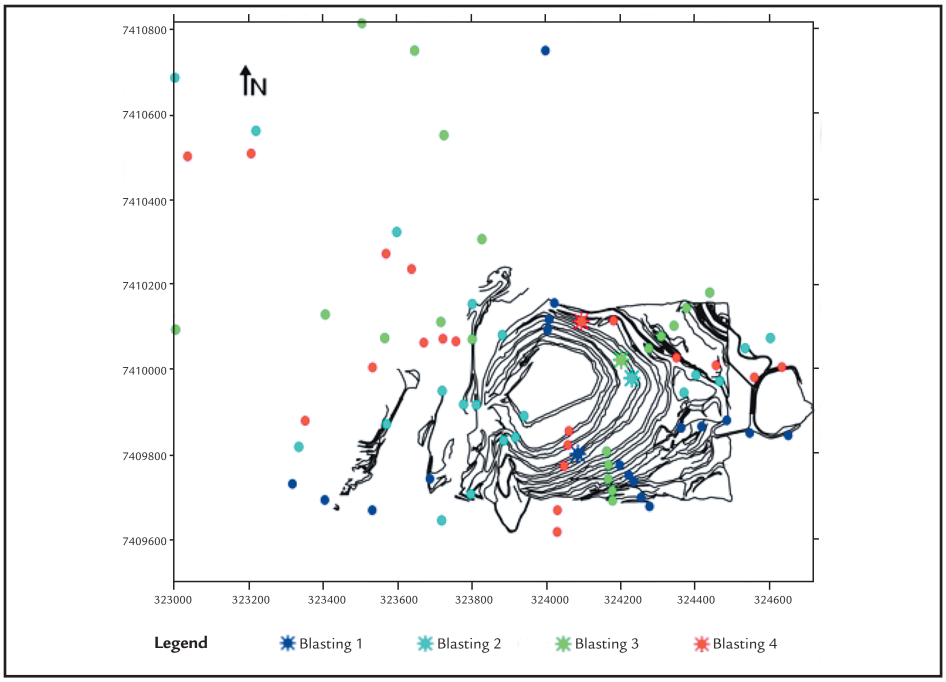

Figure 1
Blasting distribution
and location of monitored points

3. Results and discussions.

Iso-velocity maps were generated for each one of four collected blastings using PPV values and the location of monitored points (Figures 2 to 5). Surfer 8.0, a program from Golden Software, was used to create grid-based maps from irregularly spaced values (XY or XYZ data files) into an evenly-spaced grid one. The gridding method used was Kriging, a geostatistical gridding method that can express vibration trends in an accurate way (Golden Software, 2011).

It is worth noting the difficulty in placing the geophones in ideal position, i.e., five per line in 4 orthogonal directions.

As observed in Figure 4, while a line distribution was visually obtained in one of the directions, its (line) orthogonality compared to the others was not reached.

In other situations, both linearity and orthogonality were deeply compromised, as shown in Figures 3 and 5.

The greatest practical difficulties for ideal location resulted from access and topography issues.

It can be concluded that attenuations strongly depend on topography variations, lithology, positioning in the bench and blasting site.

While during the early days, Geosonics' maps used approximately 100 geophones, currently this number is as high as 150 geophones. This quantity of points may possibly increase the interpolations' precision and map similarity, since using only 20 geophones yields diverging results.

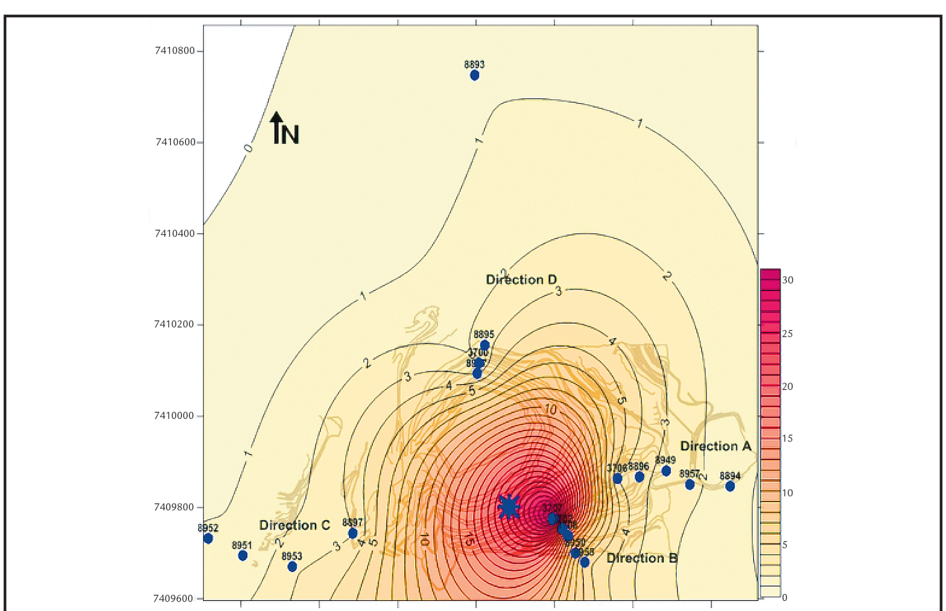

Figure 2
First blasting's Iso-velocity Map

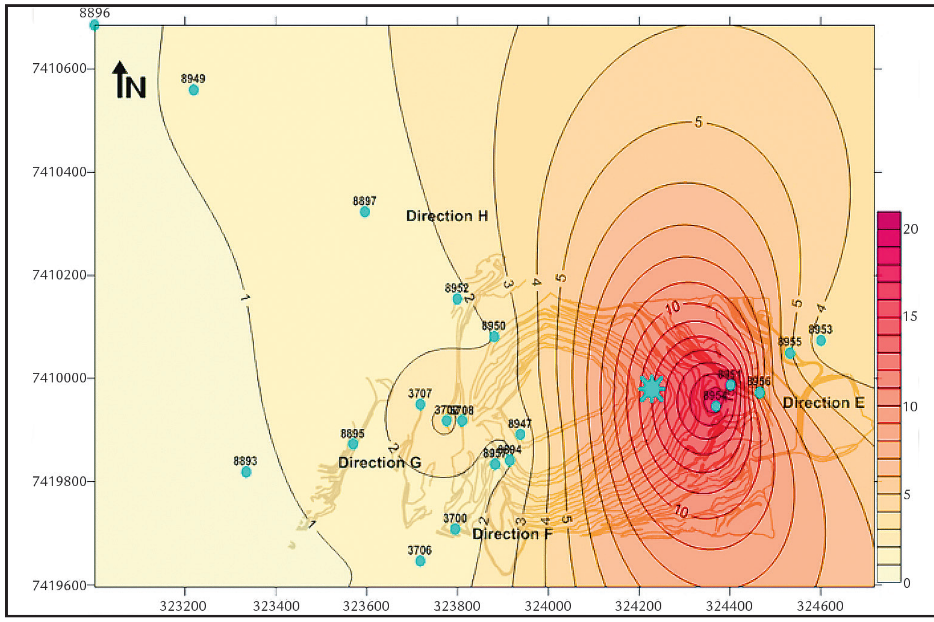

Figure 3
Second blasting's Iso-velocity Map

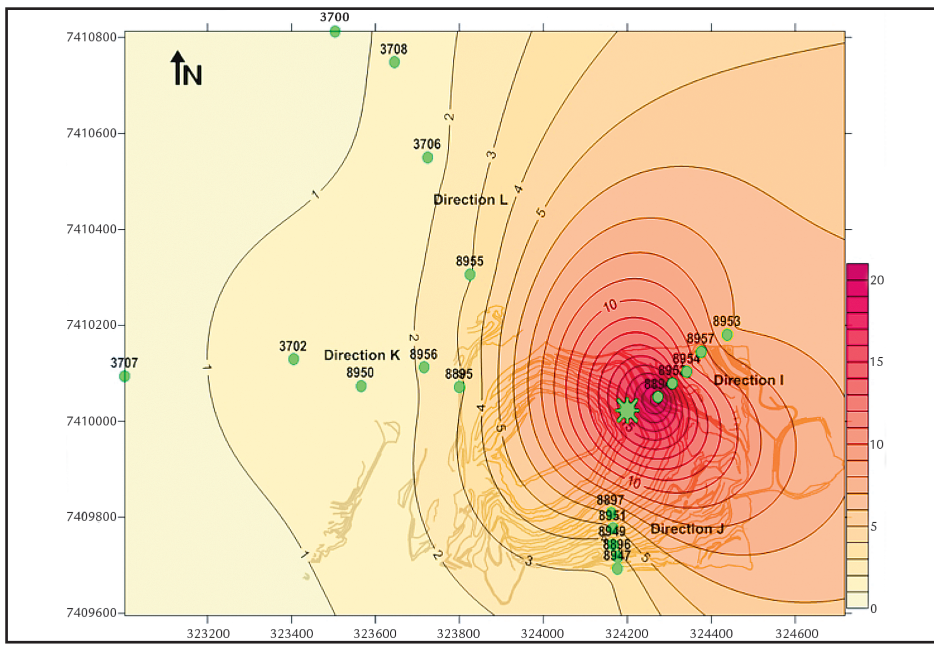

Figure 4
Third blasting's Iso-velocity Map

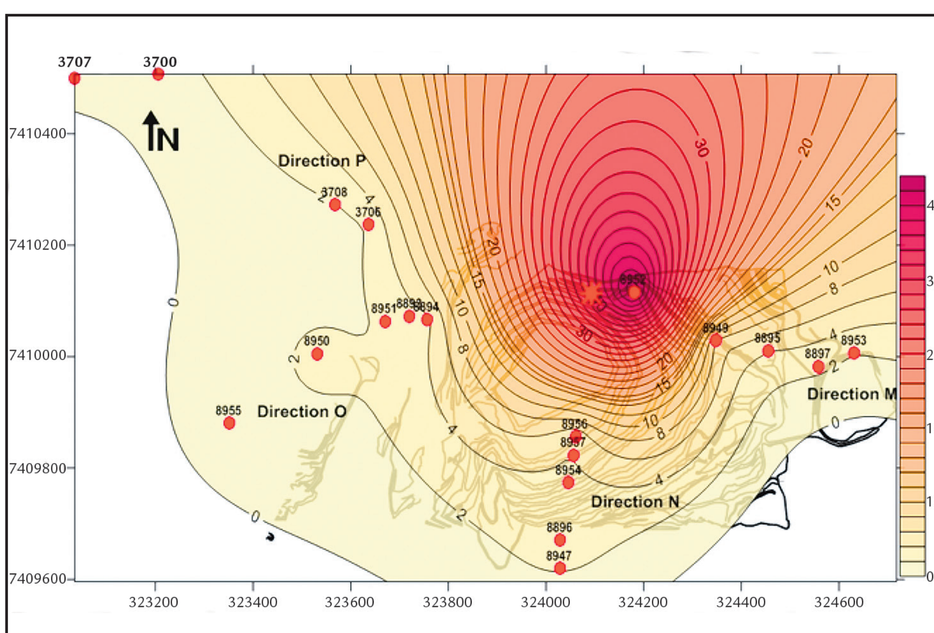

Figure 5
Fourth blasting's Iso-velocity Map

3.1 Maps simulating Iramina's methodology (2002).

Iramina (2002) developed a methodology based on a hybrid model applying the velocity vs. scaled-distance equations and the iso-velocity map concepts. There was an equipment limitation in order to generate a map based on the Geosonics model because it would have required the installation of at least one hundred sensors to obtain a good approximation for the ground vibration behavior in all directions. In fact, there was the availability of up to eight seismographs for monitoring. Eight blasts were monitored in similar conditions, and for each blast, up to eight geophones (points) were aligned towards the direction of one of the eight sectors surrounding the quarry. The results were eight equations representing vibrational behavior. These points were then plotted in a map using computer programs that interpolated and generated new waypoints of values. The result was the generation of a graphical tool with the same functionality of a true iso-velocity map that uses only eight geophones instead of more than a hundred.

The values of coefficients k and b for each of the scaled-distance equations (Table 1) and their correlating coefficients were estimated by using the values of peak particle velocity (PPV) recorded by the seismographs, distances among monitored points, blasting sites and the maximum charge weights per delay. Using a regression model, k and b can be obtained by a plotting line in log-log paper and the value of k is given by the intercept of the vertical axis, while the constant b is given by the slope of the curve. Both coefficients are site specific and therefore represent local geological rock mass characteristics.

The correlating coefficients varied from 0.72 to 0.99. Values higher than 0.80 can be considered satisfactory, and those higher than 0.90 are good. Thirteen out of 16 values are higher than 0.8 and 9 values are higher than 0.9. Jimeno *et al.* (1995) stated that 8 points would be an appropriate number, and that 5 points seem not to be enough for a reliable scaled-distance curve.

Average lines were plotted in each one of the directions monitored from a common origin, and 50 m apart points were generated on these lines following the determination of scaled-distance curves' coefficients. PPV values were then recalculated in these points using scaled-distance equations of each one of the directions, as proposed by Iramina (2002).

Direction	Equation	Coefficient of correlation
A	y = 650.01 x -1.488	0.90
B	y = 12681 x -2.445	0.99
C	y = 1958.6 x -1.702	0.72
D	y = 53.304 x -0.874	0.85
E	y = 1651.7 x -1.697	0.98
F	y = 71.455 x -1.018	0.93
G	y = 1683.7 x -1.676	0.90
H	y = 25.172 x -0.691	0.82
I	y = 90.484 x -0.757	0.98
J	y = 492.76 x -1.436	0.87
K	y = 3768.6 x -1.906	0.73
L	y = 2685 x -1.75	0.90
M	y = 1805.6 x -1.688	0.99
N	y = 83.056 x -0.893	0.76
O	y = 386.94 x -1.324	0.80
P	y = 3395.1 x -1.882	0.95

Table 1
Scaled-distance equations

Then, iso-velocity maps with 8 directions were generated (Figures 6 and 7), selecting two directions per map quadrant.

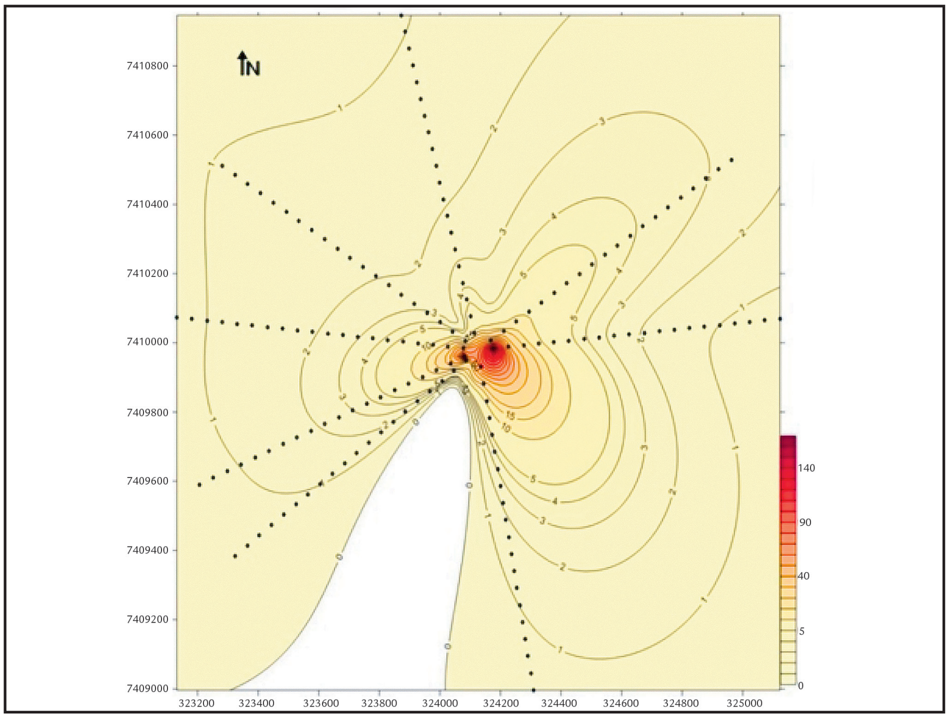

Figure 6
Iso-velocity Map with a combination of directions C, D, E, F, H, I, J and O

One can notice that maps made with points distributed in octants allow a better interpolation, although Figure 6 still shows a region with no sequence of iso-lines.

Figure 7 presents a better iso-line distribution in spite of considering the presence of a quadrant with no monitored point.

Map quality requires at least 8 points in every direction, i.e., iso-velocity maps must be created by collecting a minimum of 64 points.

Iso-velocity map usefulness depends on its reliability, which strongly depends on mathematical interpolation. Therefore, interpolation quality strongly depends on the number of collection points and their spatial distribution. Again, for the purpose of this study, Kriging gridding has proven to be useful by generating visually appealing maps from the irregularly and not so numerous spaced data set.

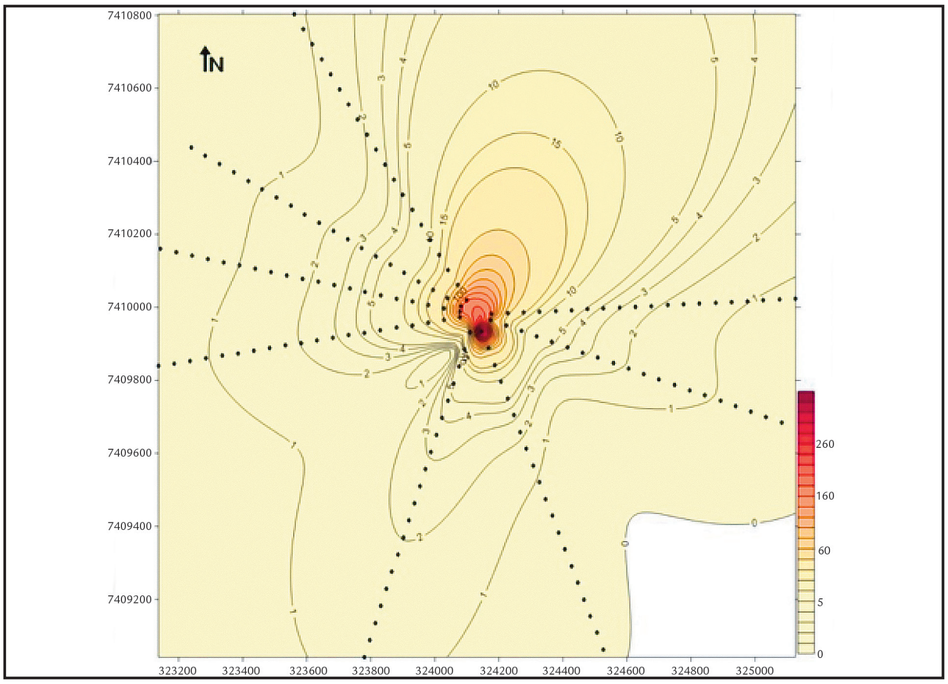

Figure 7
Iso-velocity Map with a combination of directions A, B, G, K, L, M, N and P

Geosonics Inc. has started making maps with 100 points and currently uses 150 (or more) points. This study demonstrates the real need for approximately a hundred points for a quality-bearing map. However, using a hundred geophones demands a high budget for application and equipment maintenance, in addition to a numerous field team with complex monitoring logistics.

4. Conclusions

Main conclusions may be stated here. Scaled-distance curves must be obtained using 8 or more geophones. Their correct alignment yields better correlation and a value higher than 0.9 means that the resulting line is well fit to analyze the attenuation of vibrations through the rock mass. Eight geophones provide an acceptable result, i.e., 20, 30 or 40 geophones are not required.

Iso-velocity maps must be built for a single blasting, using several geophones. The minimum acceptable quantity is approximately 64 geophones (8 octants, with 8 points per octant).

Iramina's technique (2002) should work for any kind of topography as long as the seismographs are homogeneously distributed.

The geographic geophone distribution depends on the collection purposes. In order to obtain a scaled-distance curve for a specific direction, 8 to 15 geophones must be positioned with the best possible alignment. In order to obtain an iso-velocity map, at least 64 geophones must be placed in a regular grid. A wide spatial coverage is intended, i.e., no point linearity is aimed.

Care must be taken regarding the results from mathematical interpolation. Many points within a few zones tend to distort the reality due to effects from the use of a purely mathematical technique. It is preferable to have a smaller number of spatially spread points than many points concentrated in only a few zones.

Iso-velocity maps with about 20 points can give a macro view of the real iso-lines, provided that there is a good spatial distribution. If possible, the maps must be made using more than 64 points, allowing interpolation, in order to provide maps well fitted to the rock mass when considering its anisotropy.

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