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ROCK BLASTING ANALYSIS FOR VIBRATION CONTROL AND SCENARIES SIMULATION APPLYING O-PITBLAST SOFTWARE: A STUDY CASE IN SAN CARLOS-ANTIOQUIA

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ABSTRACT

Blasting simulation methods are essential for the success of all projects for reaching proposed objectives and minimizing risks. In the following research, it was made a study of case of a blasting made under San Carlos´ Bridge in Antioquia, Colombia, with the purpose of protecting the stapes using detonating cord as a fund delay and Emulind S explosive, analyzing vibration data with O-PITBLAST cell phones and correlating the design to the rock mass. It was used the PPV method or attenuation law and consequently, data obtained by the equipments were simulated. It was possible to conclude that the vibrations taking have the effectiveness for predicting and mitigating risks, not only for the project, but also for nearby buildings. Likewise, it was determined that drilling must be parallel to diaclasas with trained and experimented staff. Also, the detonating cord as fund delay causes a shotgun effect in the basin. Limitations of the following study are based principally in the ignorance of geology and geotechnics in the testing place, and its possibility of including these variables in the development of the project.

Keywords: controlled blasting, attenuation law, blasting technology, vibrations, and constructions.

1. INTRODUCTION

Drilling and blasting using commercial explosives are used widely in a national context as an economical resource in construction, mining or quarry projects. In this context, a part of the explosive energy is always used in elastic wave form during the excavation of rocks blasting. These waves which go in all directions from the explosion epicenter provoke vibration on the ground, when they are excessive, what could cause considerable damages in nearby buildings [1] [2] [3] [4]. Vibrations on the ground induced by explosion are characterized by two important parameters: the particles maximum velocity (PPV) and the frequency. The damage potential of ground vibrations is quantified in a big scale, even in terms of PPV [5] [6] [7] [8] [9] or PPV and its associated frequency [10] [11] [12] [13] [14]. As a consequence, based on [4] the prediction of vibration levels of the ground in different distances from the blasting epicenter, the evaluation of its impact on nearby structures and the different methods for minimizing vibration levels on the ground, have a considerable role on the successful application of the drilling and blasting for rock excavation in construction, mining or quarry projects. The scope for structural damage produced by explosion vibration depends in a huge scale on the quantity of explosive charge used, the distance from the explosion place, the properties of the means in which vibrations are transmitted and the variety of designing parameters of the explosions, also, the properties and characteristics of the analyzed structure [15] [16].

According to National Fire Protection Association (NFPA), about the vibration control using explosives [17], the use of seismographs results unpredictable for a meticulous analysis and then avoiding possible damages [18]. Then, the blasting procedures which are closed to residential areas produce preoccupation on the community because of the vibrations that could be produced [19].

Seismograph is used for receiving any ground movement. In other words, it catches all mechanical waves that are spread on the elastic context [20]. The objective of this equipment is to size vibrations caused by rock blasting. These evaluations are used for intensity analysis in which the wave is spread, having a method for decreasing it [21].

On the other hand, the blasting simulation using new technologies can be seen as another risks prevention system generated by vibrations [22]. In the same way, they can help to the blasting designing in terms of PPV control and prediction on the ground, for estimating and managing damages generated by explosions [23].

In the following research, it was analyzed a 250 cubic meters of hard rock (2, 6 density) blasting, which was under San Carlos´ Bridge, Antioquia, Colombia, with a 2 meters gauge, as can be seen in the Figure-1, made on November of 2018, with the purpose of protecting the San Carlos Bridge stapes, built by LATINCO Enterprises in the same date.

Figure-1. Rock to explode in San Carlos´ Bridge, Antioquia. Resource: authors.

In the same way, the objective of the blasting was that the rock did not block up the river flow and weaken the stapes of the bridge. Likewise, an important background was considered: in 2017 an implosion on the previous bridge was made, and as a consequence, the foundations were left on the river bed, as can be seen on the Figure-2.

The research and use of technology allowed to improve the estimate of resultant vibrations of a rock blasting in nearby areas, incorporating uncontrolled parameters, like geological and geotechnical characteristics, and controlled like geometrical variables such as: drill diameter, bench height, charge, spacing, perforation, tilt of the holes and decoupling ratio [24].

Figure-2. Imploded bridge using explosives by Colombian National Army [25].

Vibration phenomena associated to rock blasting are always related to possible damages to natural or human structures.

Vibrations associated to environmental impacts, are frequently the beginning of conflicts between communities, so that the minimization of its effect results a challenge and a fundamental objective for blasting engineers [26].

For understanding the vibration phenomena in a better way and to allow a clear comprehension, it is common to compare to seismic phenomena (sinusoidal waves) [27], what allows to generate and define influence areas of vibration.

For defining the vibration, seismographs were used through the cluster analysis technique, to make easier the classification of data with a certain grade of similarity [28].

2. METHODOLOGY

The methodology for this research was developed from the study case of a rock blasting under San Carlos´ Bridge in San Carlos, Antioquia, where the rock mass was taken as a starting point. The design of the rock blasting, the opened sky blasting given by the contractor, calculations and documents elaborated on the work and the analysis of the formulas [29]. Consequently, from a results analysis obtained from vibrations and explosives of blasting made.

2.1 Conditions of the Study Place

The collapse of San Carlos´ Bridge collapse in the first semester of 2017 was associated to lateral undercut, produced by the flow and cause of San Carlos´ River. The stape was affected in the Granada´s side as can be observed in Figure-3. It proves the decrease of geomechanical properties on foundation material, visually identified as a “saprolito” of the rocky outcrop in the sector.

Figure-3. Collapsed San Carlos´ Bridge in Antioquia. Source [30].

It is of note the low protection even when the stapes were undercut, what caused the lost of foundation material and the inclusion of water on the approaches because of the increase in elevation of inundation or water sheet [30].

On previous studies observing the blasting during June of 2018, researches visited the place with the purpose of studying the structures to defend, and in the same way, to analyze the implosion effects made by National Army on December 22 of 2017 in the collapsed bridge. It was possible to see that vibrations provoked minor damages on nearby houses, as can be seen in 4 and 5 Figures.

Figure-4. Damages caused by implosion on San Carlos´ Bridge, Antioquia on December 22 of 2017. Source: [25].

A first conclusion is that affected households were localized less than 5 meters from the river bed, on slopes of 90 degrees and at 3 three meters high, as can be seen on Figure-6.

Figure-5. Implosion Works made by Engineering Battalion N. 4 "Pedro Nel Ospina general" on the bridge. Source: [25].

Figure-6. 3 meters high slope on San Carlos´ River rivera, Antioquia. Source: [25].

2.2 Rock Characterization

The rock to blast is a batolito type from Antioquia, with a density of 2, 7 gr/cm3. It is a igneous body that emerges on Central Range in Antioquia [31]. The low resistance to alteration of the batolito rocks from Antioquia makes a weathering profile with variable thickness inside the region, where is really common to find residual hetereometric spherical blocks partially weathered. One of the batolito´s characteristic is its lithological homogeneity where approximately the 92% is made by tonaltegranodiorite [30].

Rock mass was defined with a RMR (Rock Mass Rating) valuation type II, with a geomechanical valuation of 66 for good rock.

2.3 Blasting Design

CAB ENGINEERS S.A.S. and DIVOCOL S.A.S. audit enterprises were in charge of the project. They also made the rock blasting from November 27 of 2018, as can be seen in Figure-7, according to designs, for a total of 13 blasting made.

Figure-7. Rock blasting made on November 27 of 2018 at 19:55 hours in San Carlos, Antioquia. Source: authors.

It is proposed to make the blasting vertically, due to the proximity of the river level, with a 1 meter burden drilling mesh for 1 spacing meter of shaped form, making a precut row without explosive charge parallel to stapes of the bridge with a 10 meters distance. The nearest living place is from 90 meters with 2, 3 meters benches.

For reducing vibrations on nearby structures, the contractors organize the initiation mesh with MS exeldelays not electrics INDUMIL brand and establish times between 25, 50, 75 and 100 milliseconds.

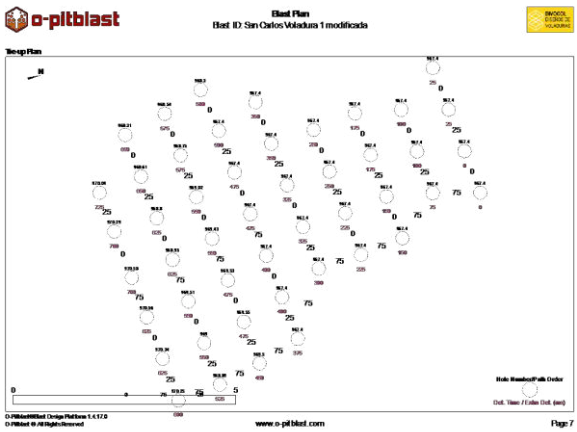

Figure-8. Initiation mesh San Carlos Antioquia, Blasting. Source: [32].

During the intervals where delays were not used, a 3 grams detonating cord was used. It is made by Military

Industry in Colombia. Thus, blasting had 725 milliseconds duration, as can be seen in Figure-8.

2.3.1 Explosives

For calculating the drilling and blasting mesh related to the explosive to use and considering the 2, 7 gr/cm3 rock hardness, EMULIND E was used, taking in consideration García and Lopez´ formulas [24], adjusting the charge factor in a 0, 6 Kg of explosive per rock cubic meter, without surpassing the threshold of 1. Then the explosive weight was compared to the determined basin which was fired in the same time, but first, Burden was calculated as the first parameter in the design, as is possible to see in equation 1:

$$B = \left(\frac{D1*2}{D2}\right) + 1{,}8 * \left(\frac{D3}{25{,}4}\right) * 0{,}3048 \quad (1)$$

Being B burden or rock (meters), D1 is explosive density, D2 the rock density and D3 s the explosive diameter. Considering this parameter the formulas for estimating the weight, spacing, length, area, energy, volume, shooting mass, power factor and energy factor were derived. In the principal calculations for estimating the design, is the weight of the explosive per basin. See equation 2:

$$P = L * D = 2{,}71 \text{ Kg. Aprox. } 2{,}47 \text{ Kg.} \quad (2)$$

Where P is the explosive weight in kilograms (Kg), L is the length used by the explosive in the basin in meters (m), see equation (3), and D is the density of the explosive used in the blasting, which in this case was EMULIND D with 1, 18 gr/cm^3.

$$L = A * T = 1{,}66. \text{ Aprox. } 1{,}90\text{m} \quad (3)$$

Where A is the effective basin height, expressed in meters see equation 4, and T is the averaged block of the basin.

$$A = H * T = 2{,}60 \text{ m} \quad (4)$$

Where H is the height of the bench calculated in meters. The explosive charge is inside of the basin in a hooded form with EMULIND E explosive in the following form, as can be seen in Figure-9:

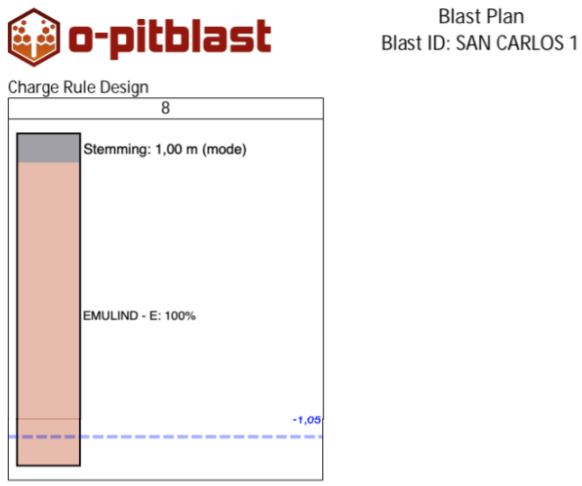

Figure-9. Basin diagram in San Carlos´ Blasting.
Source: authors.

2.3.2 Vibrations

For vibrations calculation García and López [24] were considered in associated factors like the blasting geometry, the type of rock, free face, type of explosive, distance to the structure to protect, and is the Peak Particle Velocity (PPV) what gathers these factors, represented in equation 5, predicting the maximum charge of explosive in the blasting.

$$u = a(\mathcal{R}/\mathcal{W}^{\frac{1}{2}})^m = 7{,}94\ mm/s \quad (5)$$

Where $u$is the PPV mm/s, $\mathcal{R}$ is the distance to the structure to protect in the blasting, $\mathcal{W}$ is the instant maximum charge per delay Kg, and a, m is the ground factor, obtaining a PPV of 116 mm/s, because of the K factor of normal confinement assumed in 1140 and not over passing the charge per delay of 16 Kg of explosive.

In that sense, the maximum charge per delay 16 Kg is compared as is presented in equation 6, with the weight of the explosive per basin calculated in 2, 47 Kg, as can be seen in equation 2. Without over passing the maximum limits allowed by attenuation law [33], it can be seen in Figure-12.

$$Q = (V/R\text{^}(-1{,}6)\ )\text{^}1{,}25 = 16 \text{ kg} \quad (6)$$

Where Q is the maximum charge per firecracker, V is the PPV in mm/s. Seismographs used were cell phone applications from the software O-PITBLAST put in different distances in each blasting, reporting the movements maximum levels, as can be seen in Figure-11.

Figure-10. a. Special and Controlled blasting in San Carlos, Antioquia. Source: authors.

Figure-10. b. Special and Controlled blasting in San Carlos, Antioquia. Source: authors.

3. RESULTS

On vibrations reported in San Carlos, O-PITBLAST simulation [32] was applied. Having the 13 blasting data where the blasting hour, the longitudinal, transversal and vertical limit, the distance from the cell phone to the operation basins and the maximum charge per firecracker (MIC) used on its respective blasting, as can be seen in chart-1.

		X	Y	Z				
Day	Hour	Longitudinal	Transversal	Vertical	Distance	MIC	Blasting	Anotation
27.11.18	19:55:13	24,9	26,8	41,4	9	10,3	1st. Blasting	Night blasting
28.11.18	17:49:55	42,3	24,9	20,9	10	12,5	1st. Blasting	Secondary blasting
29.11.18	16:07:27	0,3	0,2	0,2	5	5,5	1st. Blasting	Secondary blasting and half of the river
2.12.18	13:08:37	59,7	39	23,5	10,5	15,5	2nd. Blasting	1st and 2nd row blasting
2.12.18	15:30:33	5	18,5	3,1	9	9,5	2nd. Blasting	Crest blasting
2.12.18	15:30:52	8,3	10,1	6,6	9	3,5	2nd. Blasting	Secondary blasting in the 1st and 2nd row
3.12.18	15:10:09	0	0	0	8	4	2nd. Blasting	Secondary blasting crest
5.12.18	12:37:06	0,8	38,2	34,8	10	6,3	2nd. Blasting	Rock and plaque blasting inside the river
6.12.18	10:37:53	45,7	24,8	38,8	11	1,6	2nd. Blasting	Secondary blasting rock in front of the river plaque
6.12.18	10:38:04	42,6	27,8	28,7	11	9,7	2nd. Blasting	Blasting row number 5
7.12.18	17:10:04	10,7	14	2,3	20	3,9	3rd. Blasting	Blasting on the fallen plaque in San Carlos´ River Bridge
7.12.18	17:11:52	7,7	5	2,8	20	3,9	3rd. Blasting	Blasting on the fallen plaque in San Carlos´ River Bridge
7.12.18	17:11:59	6,2	2,8	3,1	20	3,9	3rd. Blasting	Blasting on the fallen plaque in San Carlos´ River Bridge

Chart-1. Seismographs data (O-PITBLAST cell phones) taken on ground. Source: authors.

4. CONCLUSIONS

It was proved that experimental essays using cell phones, according to Figure-11, with the usage of O-PITBLAST seismographs showed data, seen in chart-1, which reflect a solution for the differential equation that governs the attenuation law behavior, according to equation 5.

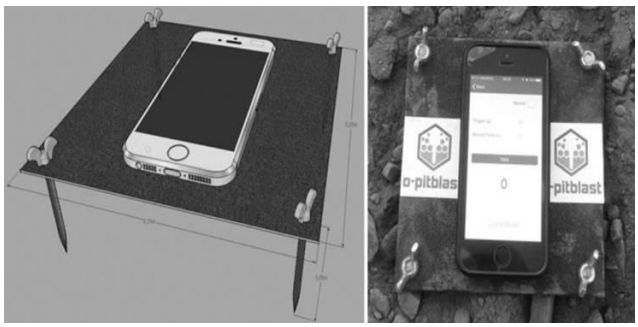

Figure-11. Cell phones with seismograph application O-PITBLAST. Source: [32].

In that sense, blasting opened sky exercises were made, as can be seen in figures 10a and 10b, using the O-PITBLAST software. It was made an experimental

analysis proposed by Vinicius Miranda and Francisco Sena Leite [22], and García López [24], with the purpose of verifying the proper behavior of the vibrations, the control of the detonating cord in drilling and to see if the perforation made on therock produced the expected results in the blasting, reducing smoke and noises risks.

In such a way, the blasting was made without damages on the stapes or nearby structures during the 13 blasting and keeping a charge factor of 0, 6 Kg/mcb and obtaining the ideal granulometry of 1, 5 m, consistent with the charging equipments that were used for removing the material from the place.

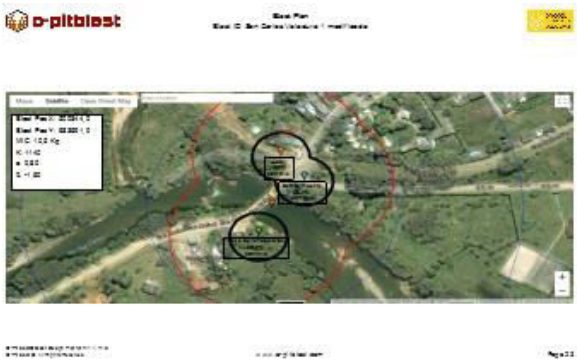

Figure-12(a). Data simulation on O-PITBLAST from the vibrations in San Carlos, Antioquia blasting. Source: authors.

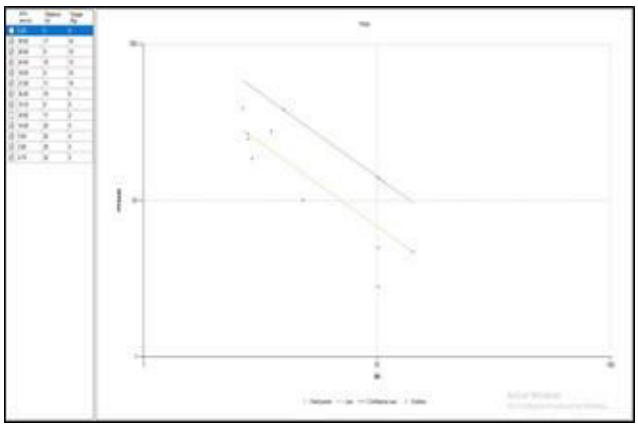

Figure-12(b). Data simulation on O-PITBLAST from the vibrations in San Carlos, Antioquia blasting. Source: authors.

In the same way, it was proved that during the process of the activity, perforation vs. rock mass must be parallel because on the contrary, the effect of the explosive could be lost and could be generated oversized, as can be observed in Figures 13a, 13b and 13c.

Figure-13(a). Drilling vs. Rock diaclasa. Source: authors.

Figure-13(b). Drilling vs. Rock diaclasa. Source: authors.

Figure-13(c). Drilling vs. Rock diaclasa. Source: authors.

It is important to say that the driller must be an experimented worker, for making the drilling on the basins, because damages could be generated during the blasting, producing over sizes and loosing explosives, as can be observed in Figure-14 a and 14 b.

Figure-14(a). Experience on drilling. Source: authors.

Figure-14(b). Experience on drilling. Source: authors.

Likewise, unknowing the performance of the explosives can generate lost of energy in the basin and produce generated risks, as could be the noise and the projections. Additionally, researchers could prove that using detonating cord as delay for fund, as can be observed on Figures 15a, 15b and 15c, generates the shotgun effect, because all the detonating cord is an explosive, therefore destroys the block of the basin, making a big expulsion of gases and energy, what obviously produces noise and projections, losing the function of the explosive and generating over costs because of secondary blasting.

Figure-15(a). Detonating cord effect as a fund detonating. Source: authors.

Figure-15(b). Detonating cord effect as a fund detonating. Source: authors.

Figure-15(c). Detonating cord effect as a fund detonating. Source: authors.

Figure-15(d). Detonating cord effect as a fund detonating. Source: authors.

In absence of particular studies about the place, as they are geology and stratification of the ground, it is expected that the developed simulation from this study can be useful for preliminaries and saved charges estimation for digging rocks in similar geological formations, which can later be improved or adapted to the real conditions of

the place through the data collection about vibration of the ground during the real blasting operations.

In later studies, uncontrolled variables of parameters must be taken in consideration. For example, geologic and geotechnic characteristics must be considered for estimating precisely the extension of the damage produced on nearby structures, this, because the vibrations on the ground induced by the explosion depend on the parameters of ground movement, the design of the explosion and the type of geological stratums in the base, also its inherent resistance and dynamical properties.

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