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Original scientific paper

OPTIMIZATION AND ANALYSIS OF DRILLING AND BLASTING PARAMETERS USING O-PITBLAST SOFTWARE

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Abstract: The development of modern technologies has enabled the application of specialized softwares in the field of mining through various segments and processes, including in works related to drilling and blasting. The application of specialized software for drilling and blasting with the use of modern technologies such as photogrammetry enabled more accurate data from the field for later processing. By processing data and creating a 3D model of the terrain for drilling and blasting works, it can obtain precise data, which serve us for the optimization of drilling and blasting parameters, as well as their analysis. The application of this type of specialized software, in this case, the O-Pitblast software, provides an overview of all parameters, as well as possible corrections and different scenarios regarding the results of the blasting itself. Optimization and analysis through this software can improve the results of blasting in terms of fragmented material size, and reduce the unwanted effects of blasting, such as the flyrock or blast vibration. The software has different types of tools that allow a detailed review and insight into the entire process from the beginning of planning drilling and blasting works to the very end and also printing of reports after the work is done.

Keywords: optimization; 3D model; drilling; blasting; O-Pitblast; software

1 INTRODUCTION

Mining industries and others have developed computer softwares for solving various engineering tasks, such as in the design phase but also the exploitation process, to evaluate the performed works and optimize different operations (Crnogorac L. et al., 2019). During blasting at quarries, parameters related to drilling and blasting work need to be optimized, to see the real situation from the field now it is enabled with the revolution of specialized softwares development. The specialized softwares for drilling and blasting which are currently on the market were developed on the principle of recording aerial images with the help of unmanned aerial vehicles and processing images

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with the photogrammetry method. By processing photos, software obtains a cloud of points which, as a document, contains information about every point of the part of the terrain on which the blast is carried out or the entire open pit, according to X, Y, and Z coordinates. By importing data into the software that is specialized for drilling and blasting, it generates a 3D model and gets a detailed overview of the bench on which the blasting is being done and then can perform optimization and analysis of the drilling and blasting parameters. The combination of software with modern technologies such as UAV technology (unmanned aerial vehicle) or drones is also significant because the software can finally process the precise input data from the field (Milanović S. et al., 2019). Through this paper, an example of the use of O-Pitblast software at a quarry is given for optimization and analysis of parameters during drilling and later during blasting operations.

With the O-Pitblast software, users can monitor and analyze various parameters that affect blasting results. It is possible to analyze the fragmentation of rock material, which is affected by the parameters of drilling and blasting, such as the geometry of the blast field, the amount of explosives, delay time, etc. These parameters can be analyzed in the software, which also has tools for analyzing the blast vibration, predicting the strength of the blast vibration and its impact on the environment.

Through the analysis of the blast vibration, with the help of this software, can be imported vibration values in the database and analyzed, and the quantity of explosives per delay can be predicted and in that way avoid possible damage to buildings due to blasting. Detailed analysis is shown through diagrams according to the appropriate standards as well as by determining the attenuation law.

2 DATA IN O-PITBLAST SOFTWARE

Through the O-Pitblast software, the database allows us to enter various parameters such as the characteristics of the rock material, the technical characteristics of the explosives as well as the means for the initiation system of the explosives, and the prices of the costs for drilling and blasting works, which allows the software to choose the most suitable possible solution for the drilling and blasting parameters. For this example, the following characteristics of the rock material and explosives in the quarry were used, imported into the software database, and used through further analysis.

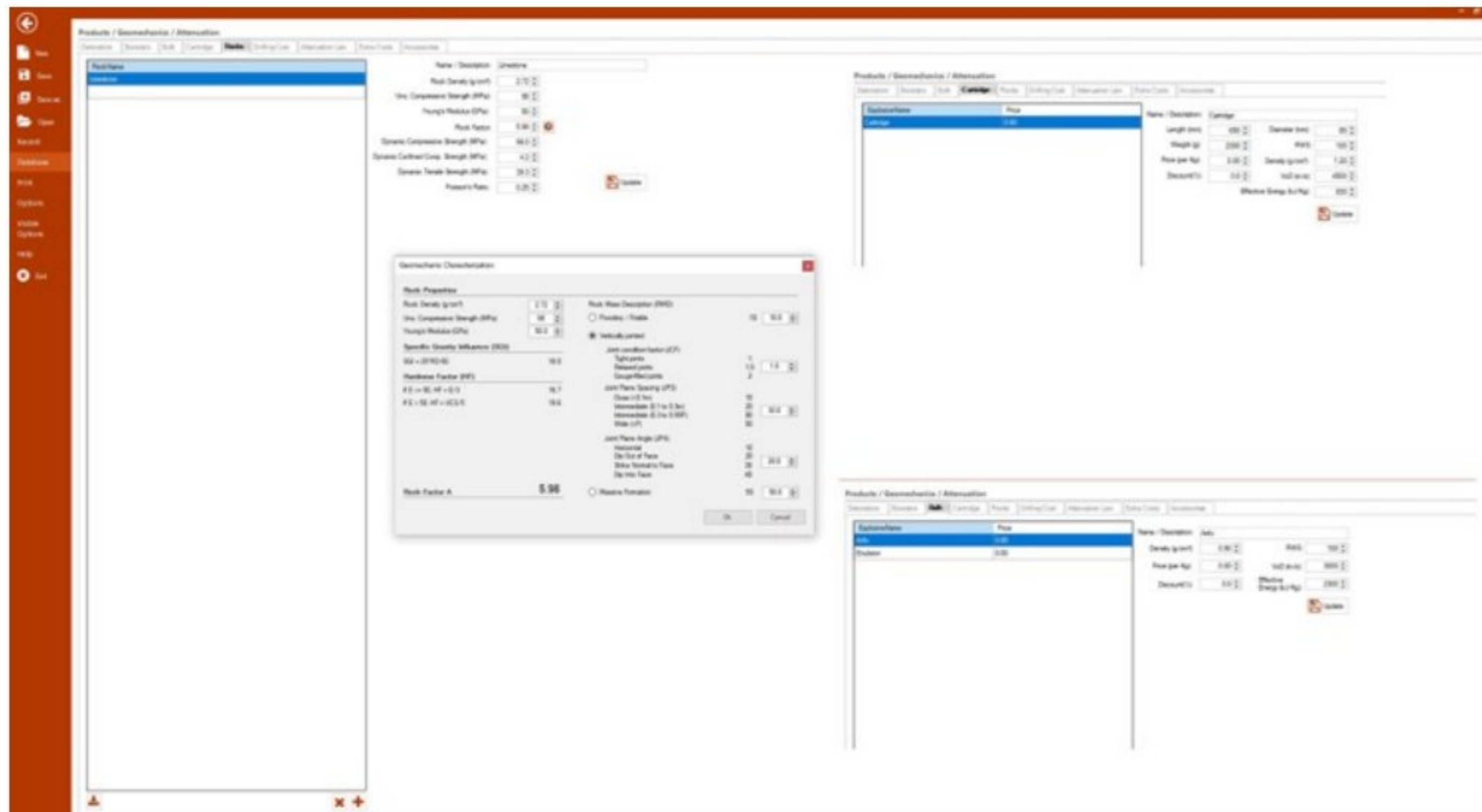


Figure 1 Creating rock material and explosive properties in the O-Pitblast software

The creation of a 3D terrain model is done based on the input of a large number of points, which are generated based on the processing of photos taken from an unmanned aerial vehicle. 3D models can be generated through the software based on a large number of points positioned in X, Y, and Z coordinates. In this case, a model of the bench was generated on which the blasting was carried out, in order to first establish the drilling parameters in the blast field, but also to optimize the blasting parameters.

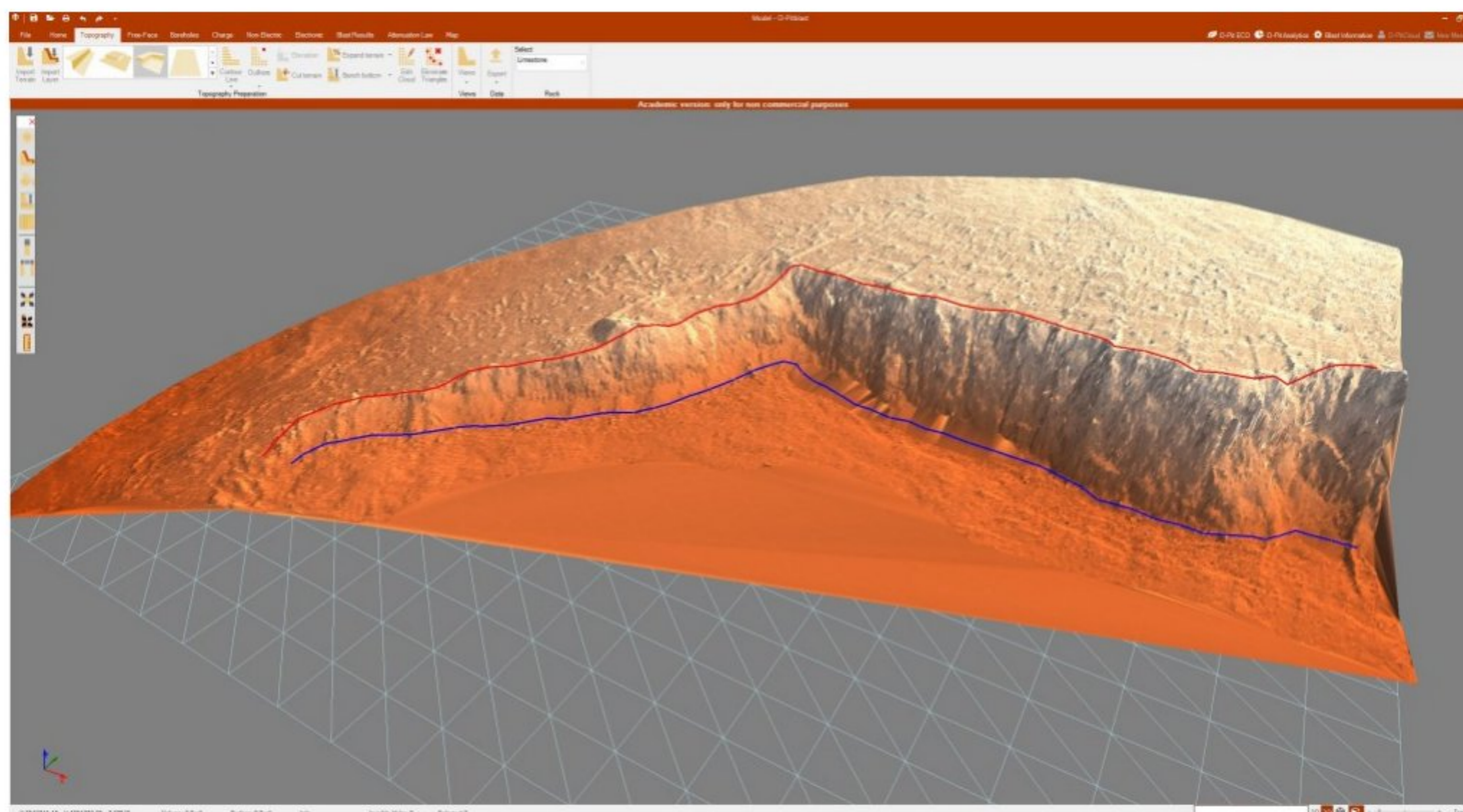


Figure 2 3D model of terrain with crest and toe of the bench in O-Pitblast software

After creating the terrain model, before designing the drilling and blasting works, it would be good to define the crest and toe of the bench, so that the drilling angle and the position of the blastholes can be checked later in the software. This tool is very important because by adjusting the angle, it can correct the burden, which is very important when blasting, especially in the first row of the blast field. Also, using tools for correcting and checking the drilling angle, can prevent the unwanted effects of blasting, such as the flyrock, but also contribute to a better fragmentation of the material and prevent the appearance of boulders.

3 DESIGNING DRILLING AND BLASTING PARAMETERS

3.1 Blastholes and designed parameters

During the blasting on the quarry, the designed parameters were used, which are shown in the following Table 1. These parameters were entered into the software so that further analysis and optimization could be carried out. Blastholes were created before entering the parameters. Blastholes are entered by using already existing templates to create positions or by entering a file with the exact positions of the blastholes in the appropriate coordinate system. The following picture shows the designed blastholes, as well as additional blastholes that would be drilled to reduce the burden size in places where it is necessary.

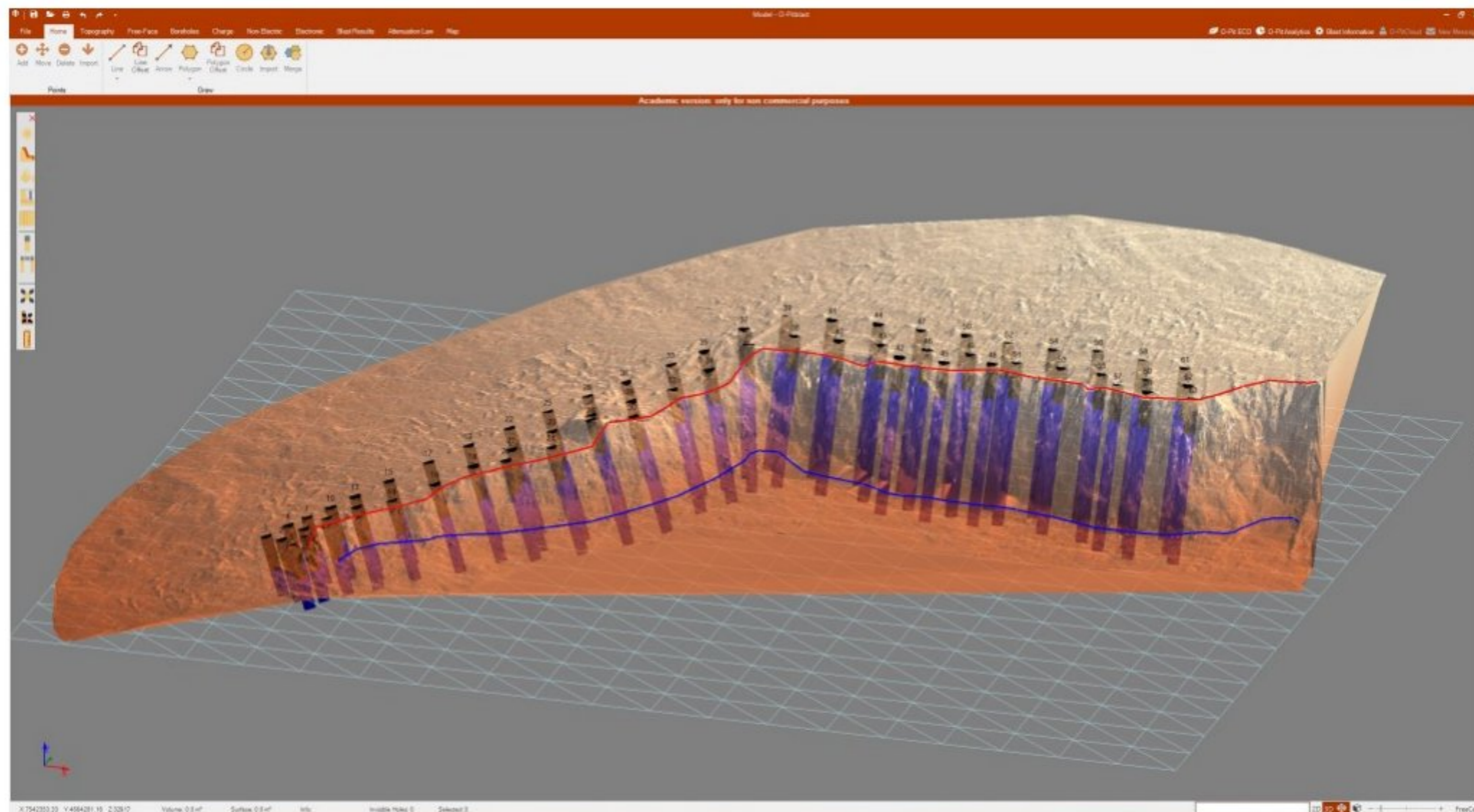


Figure 3 Blastholes for designed parameters of drilling in O-Pitblast software

The parameters of drilling and blasting on the quarry are given in such a way as to satisfy the appropriate requirements regarding fragmentation, loading, and transport mechanization, but in this example, their analysis and optimization will be performed

through software. The following Table 1 shows the design parameters of drilling and blasting.

Table 1 Designed drilling and blasting parameters

Parameters	Value
Burden	3 m
Spacing	3.6 m
Inclination of blasthole	75°
Stemming	3 m
Bench height	8.5 m
Drilled length	685.6 m
Design volume	4,935 m ³
Number of blastholes	63

The designed drilling and blasting parameters entered into the software must be analyzed in the software to determine whether they can be further optimized, to obtain the best possible fragmentation of the material, reduce the unwanted effects on the environment, as well as prevent the flyrock. First, the designed parameters are entered, where the software will give the final results in terms of the burden size, as in the fragmentation size, and it can compare the obtained results with the optimized parameters processed later to obtain the difference. We entered the designed parameters according to the existing data taken during blasting so far, then we analyzed them in the software.

3.2 Blastholes information and blast pattern

When entering the designed blastholes into the software, it allows further access to each blasthole on the blastfield, where it can fill those blasthole from the database that was previously created. In addition to entering data on explosives, we also have data on in-hole detonation delay time that we must also enter, then data on blastholes such as position, angle, depth, the quantity of explosives, etc. The biggest advantage of the software is precisely in the optimization of drilling parameters, where for this purpose the correction of the blasthole inclination can be performed separately or only the first row of the blastholes, etc. In addition to the optimization of drilling parameters, the software has tools for different types of connections in the blastfield and various scenarios, as well as analysis of the blasting results. Analysis of blast vibration due to demining, analysis of the fragmentation, the possibility of controlling the overlap of delay time, and other various options. The following Figure 4 shows the bench where the blast charge can be seen for a specific blasthole.

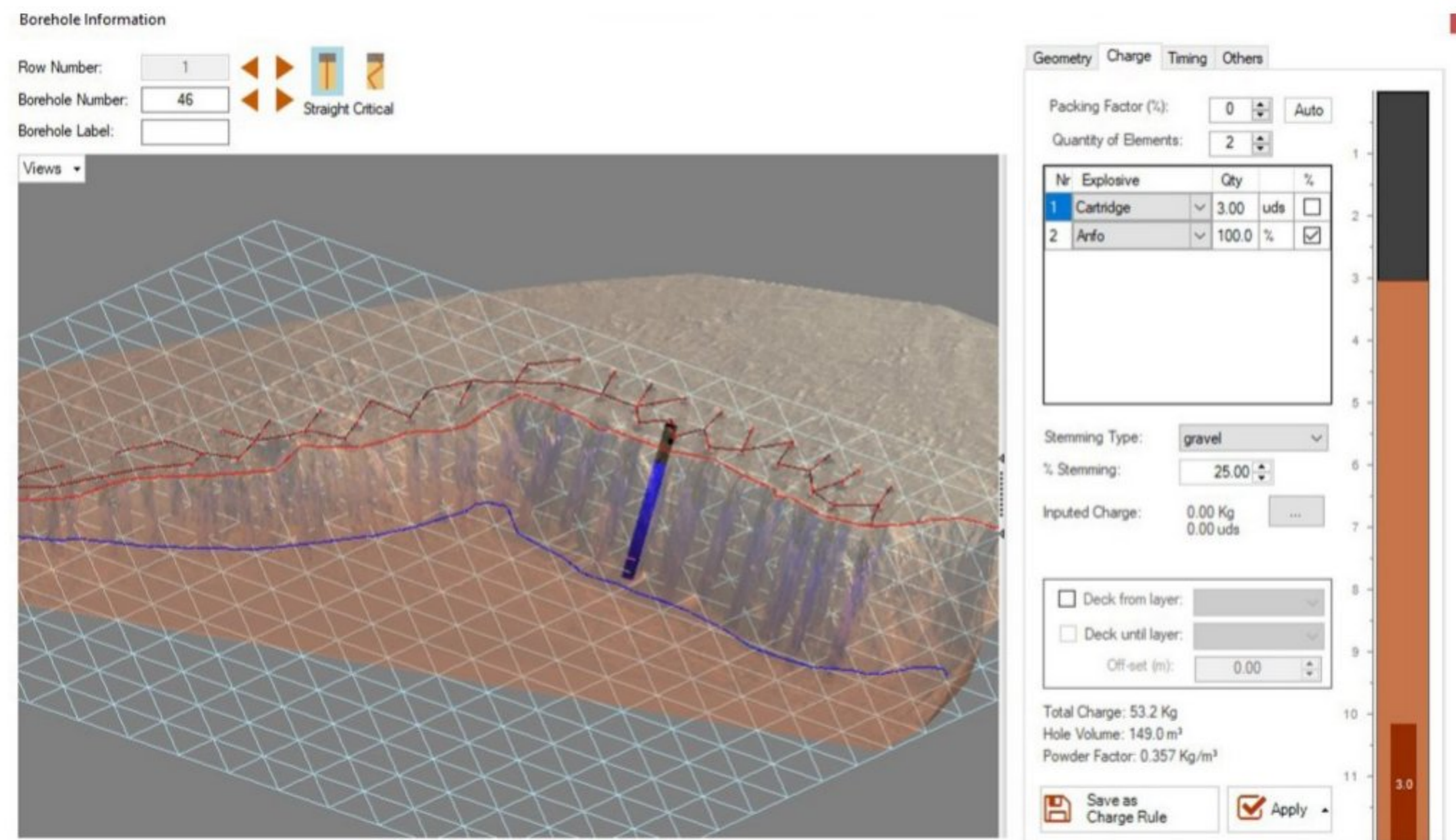


Figure 4 Blasthole charge according to designed parameters in O-Pitblast software

Blasthole is carried out as planned according to the designed parameters, and the data on the quantity and characteristics of the explosives used are shown in the following Table 2 and were also entered into the database during processing in the software. After entering and reviewing the blasthole charges, it is possible to proceed to the creation of the blast pattern, which can be used in the database for the non-electric initiation of blastholes. The Nonel system provides adequate safety during initiation, reduction of blast vibration, a combination of different delay times, use in blastholes filled with water, etc (Milanović S. et al., 2023).

Table 2 Characteristics of explosives (<https://www.maxamcorp.com/en>)

Parameters	ANFO	Emulsion
Density (kg/l)	0.8-0.95	1.1-1.3
Detonation speed (m/s)	2500-3500	2800-6000
Gas volume (lit/kg)	970	921
Specific energy (kJ/kg)	2260	2590

When entering data on the connection system of detonators, as well as on blasthole delay time, software can check the initiation system with the help of simulation, as well as whether any of the blastholes on the blastfield are initiated at the same time. Initiation of blasthole at the same time can lead to unwanted effects such as an increase of the blast vibration, so the delay time can be checked here, i.e. whether the appropriate amount that is designed for the delay time does not have the same initiation time as some of the other blasthole on the blastfield. The blast pattern, delay time, as well as delay time control system with the simulation of blasting are shown in the following Figure 5.

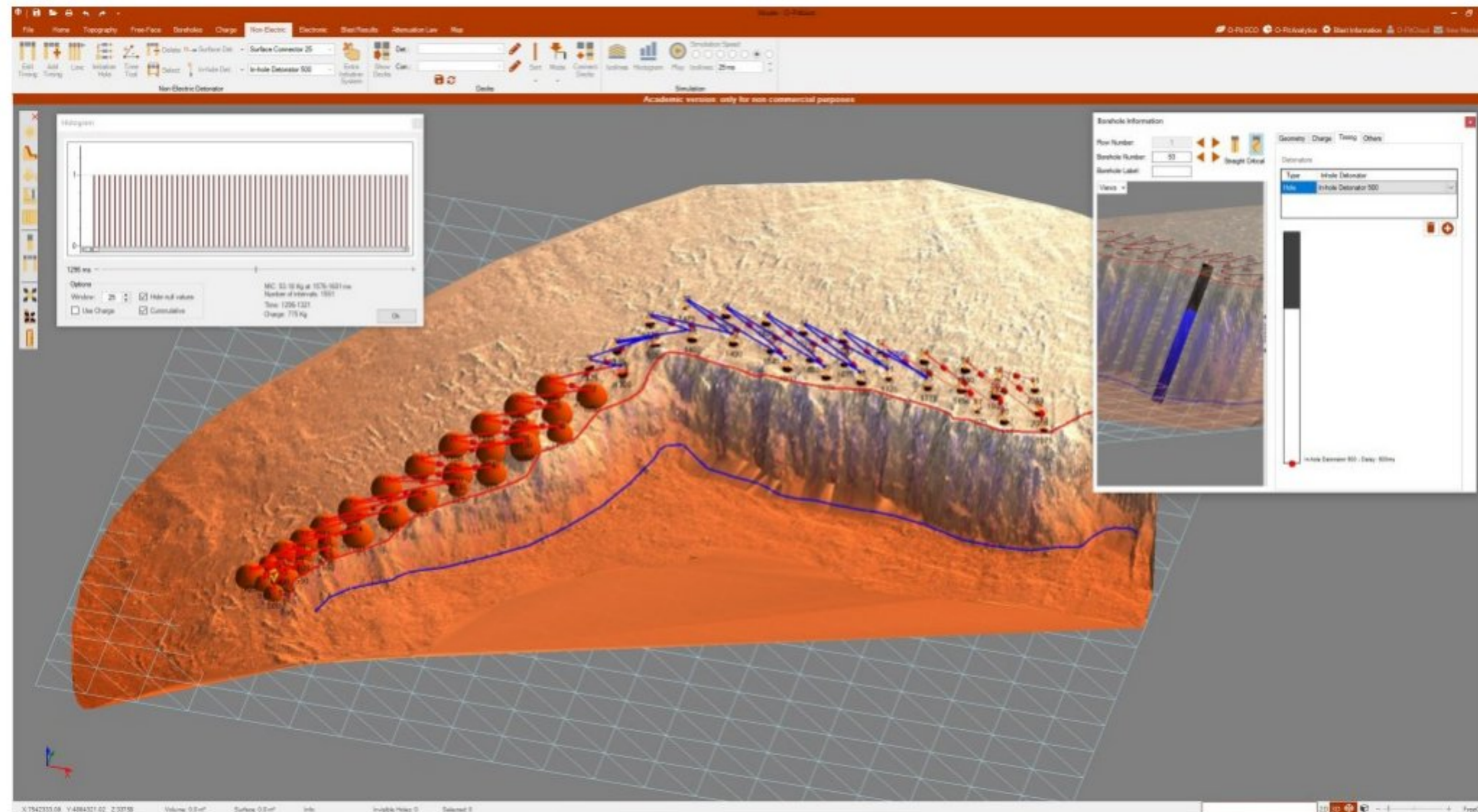


Figure 5 Simulation of blasting with the delay time in the O-Pitblast software

3.3 Burden distribution

As already mentioned in the previous part of this paper, the main advantage of the O-Pitblast software is the correction of the drilling inclination to optimize the burden size, i.e. first row in the blastfield. The burden is an important parameter in blasting, and when it is close to the designed one along the entire blasthole, the quality of the blast increases, in terms of the size of the fragmented material and also of the reduced possibility of flyrock. Correct designed burden guarantees high efficiency of rock mass blasting, and burden distribution in this software provides data of a proposed blasthole pattern by blasting documentation guideline (Pyra J. and Gądek K., 2020). During blasting in the quarry, the front of the bench is often irregularly shaped, so that in most cases the designed one burden deviates a lot, so this software enables precise data of the place of bench burden that is equal to or deviated one. The following Figure 6 shows a model with differently colored zones depending on the size of the line of smallest burden.

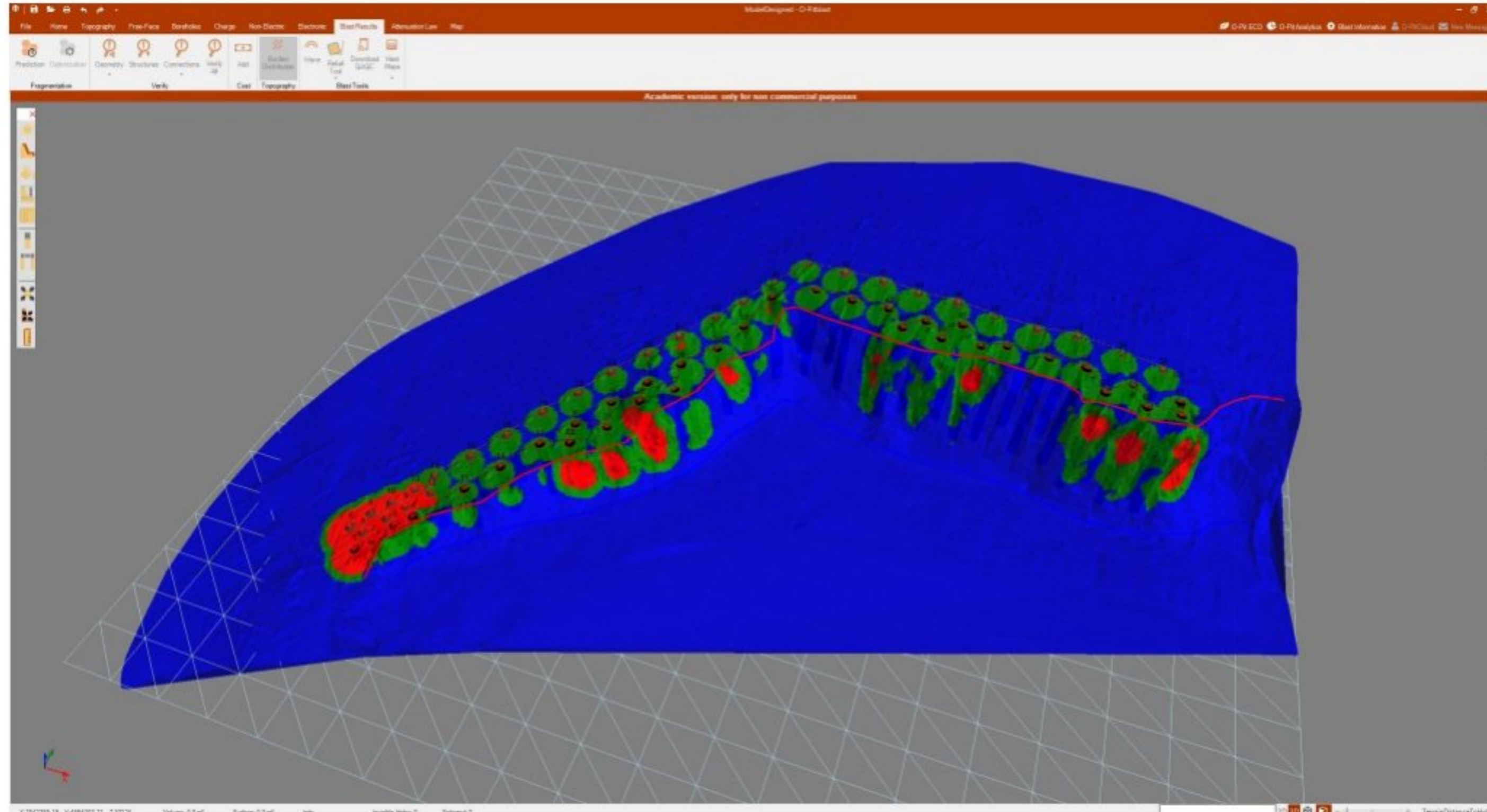


Figure 6 Burden distribution with designed parameters in the O-Pitblast software

The green color represents the zones where the burden value is close to the designed one, and the blue color represents the zones where there are larger burden deviations (the value of the burden is higher than the designed one), and the red zones represent the zones where there are smaller burden values than the designed one (Milanović S. et al., 2023). Based on this option, it is possible to predict even in which place in the blastfield there will be a problem from the eventual flyrock or even from the appearance of oversized rock material. There are three types of flyrock during blasting, which appear by lack of confinement of the energy in the explosive column, and also in the condition when there is a small burden size for the blasthole diameter (Negovanović, M. et al., 2022). Different types of flyrock are shown in Figure 7.

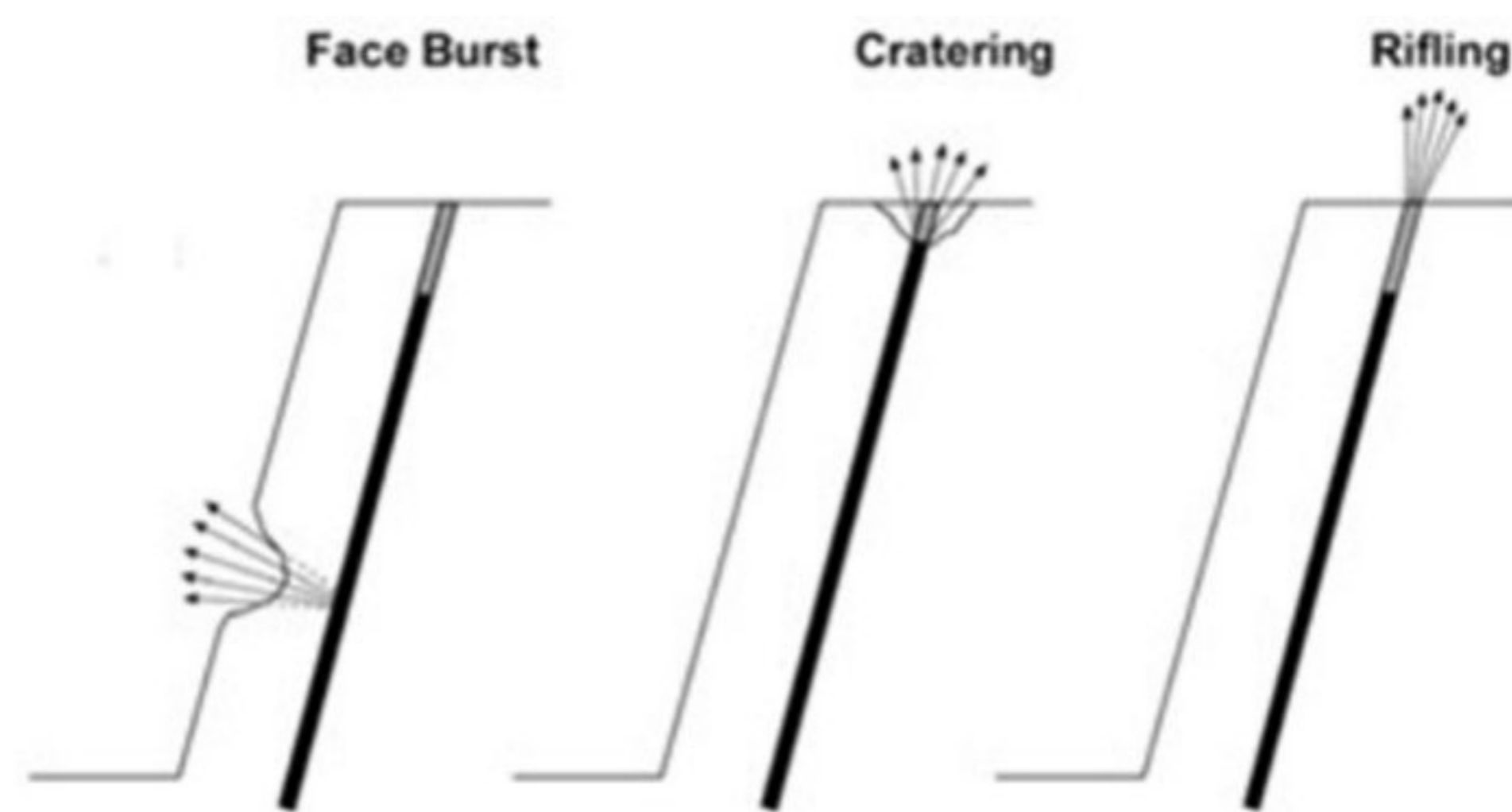


Figure 7 The three key mechanisms of flyrock (<https://www.o-pitblast.com/>)

By using the software, the inclination can be corrected before the drilling, and after the inspection with the use of burden distribution in the software, the correct values of the

drilling inclination can be obtained according to which the drilling can be done, so that the results of the blasting later are as satisfactory as possible. When calculating the zone of flyrock, the software uses three possible types of flyrock, i.e. face burst, cratering and rifling, which can be calculated using the following equations (<https://www.o-pitblast.com/>).

- Face burst

$$L = \frac{k^2}{g} \cdot \left(\frac{\sqrt{m}}{B}\right)^{2.6} \quad (1)$$

- Cratering

$$L = \frac{k^2}{g} \cdot \left(\frac{\sqrt{m}}{SH}\right)^{2.6} \quad (2)$$

- Rifling

$$L = \frac{k^2}{g} \cdot \left(\frac{\sqrt{m}}{SH}\right)^{2.6} \sin 2\theta_0 \quad (3)$$

Where:

θ - drilling angle,
 L - maximum throw (m),
 m - charge mass (kg/m),
 B - burden (m),
 SH - stemming height (m),
 g - gravitational constant,
 k - rock coefficient.

3.4 Fragmentation analysis

The software can estimate the fragmentation through the analysis of the entered drilling and blasting parameters, i.e. estimate the size of fragmented rock material. In this example, it will also compare the fragmentation size before and after the optimization of the drilling and blasting parameters. Fragmentation of rock material (size and shape) is generated depending on the rock material properties, blasting pattern (where in open pit mines often is a blast pattern with parallel blastholes, because is easier to control fragmentation), and type of explosives (Lapčević, V. et al., 2023).

The O-Pitblast software uses the Kuz-Ram mathematical model for the calculation and evaluation of the fragmentation, which takes into account several parameters in the calculation, which can be seen in the equations listed below. A correlation between the detonation energy and average fragmentation size applied per rock volume was developed by Kuznetsov (1973) as a function of the rock type. This equation was modified by Cunningham (1983) and is given by the next equation (Fonseca de Castro, D., 2021).

$$X_{50} = A \cdot K^{-0,8} \cdot Q^{\frac{1}{6}} \cdot \left(\frac{115}{RWS}\right)^{\frac{19}{30}} \quad (4)$$

Where:

X_{50} - the average particle size (mm),
 A - the rock factor,
 K - the load ratio (kg/m³),
 Q - the quantity of the explosive (kg),
 RWS - the relative weight energy (RWS)

Uniformity index equation, this expression was developed through field tests by Cunningham (1987). It correlates all the geometric parameters of the blast pattern, as follows (Fonseca de Castro, D., 2021).

$$n = \left[2.2 - 14 \left(\frac{B}{D}\right)\right] \cdot \left[\frac{1+\frac{S}{B}}{2}\right] \cdot \left(1 + \frac{W}{B}\right) \cdot \left(\frac{|L_B - L_C|}{L} + 0,1\right)^{0,1} \cdot \frac{L}{H} \quad (5)$$

Where:

B - the burden (m),
 S - the spacing (m),
 D - the diameter of the hole (mm),
 W - the deviation (m),
 L - the total load length (m),
 H - the height of the bench (m).

According to the designed parameters of drilling and blasting, the software assessed the fragmentation size, which is shown in Figure 8.

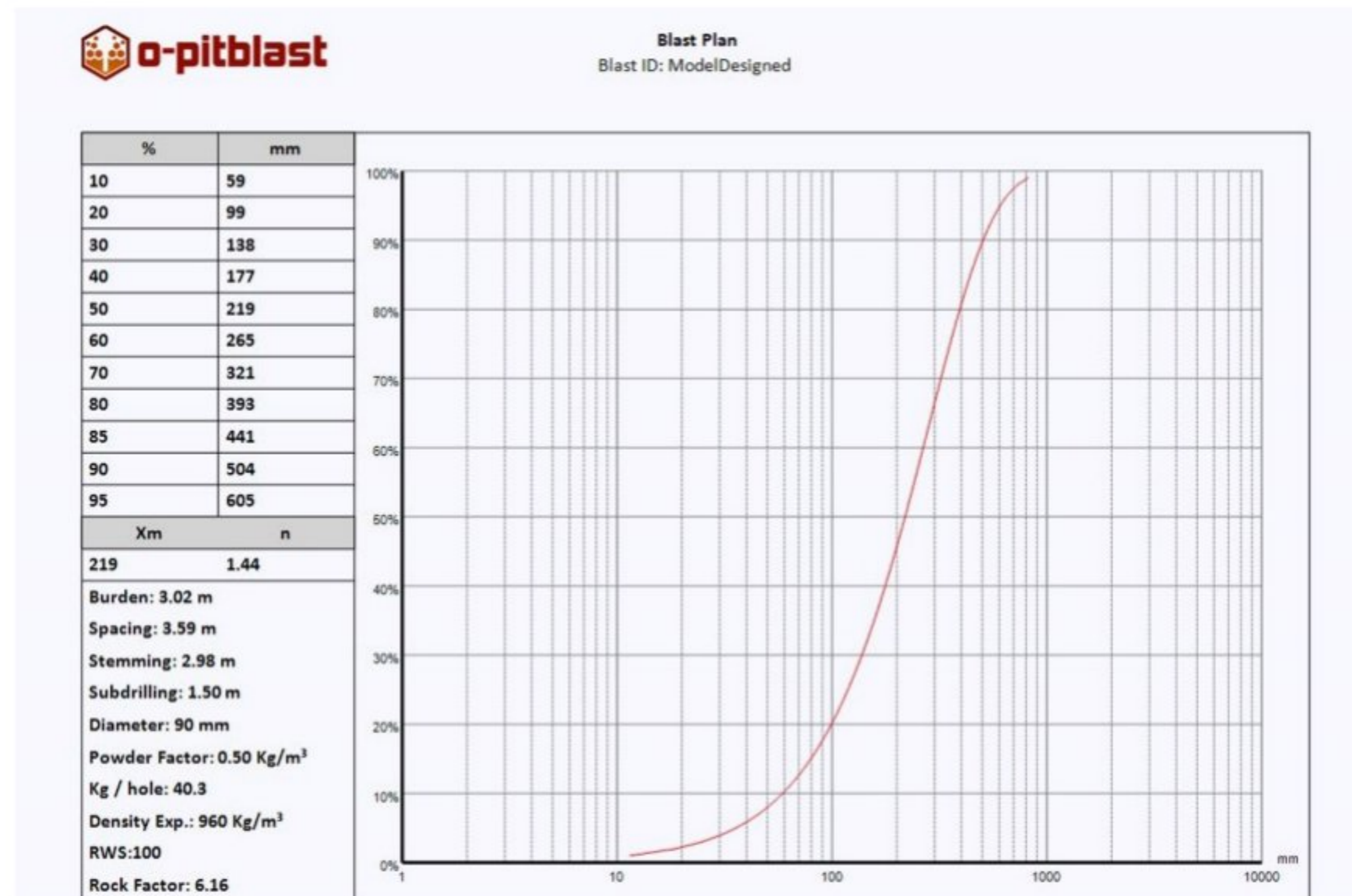


Figure 8 Fragmentation size from designed parameters in the O-Pitblast software

4 OPTIMIZING DRILLING AND BLASTING PARAMETERS

Based on the arrangement of blasthole that was made according to the designed parameters of drilling and blasting in Figure 3, where two rows of blasthole were made, and the blastfield was designed so that the last row of blasthole leaves a flat bench, and because of this, as you can see in the picture, we have a higher distance from the free face and the bigger burden. In places where the burden is bigger, auxiliary blastholes were drilled to correct the burden size and achieve better blasting results. Figure 6, shows the exact distribution of the burden on the slope of the bench, where they were drilled according to the designed inclination, while the result of the fragmentation size of the blasting is shown in Figure 8 by processing through the software.

To obtain better blasting results and reduce possible drilling costs, the parameters were optimized through software, where it will present the optimized drilling and blasting parameters, as well as the results, in the following text. The first step was carried out in correcting the blasthole pattern, with the help of the blasthole optimization tool, i.e. the first row of blastholes according to the drawn crest and toe of the bench. Such an arrangement of blastholes with the same drilling angle as with the designed parameters contributes to the fact that we have a precisely determined burden size on the entire slope. In this case, the second row of blastholes follows the first, so that the last row would leave a flat bench, the addition of blastholes was made, but this time in the last row, which is shown in Figure 9.

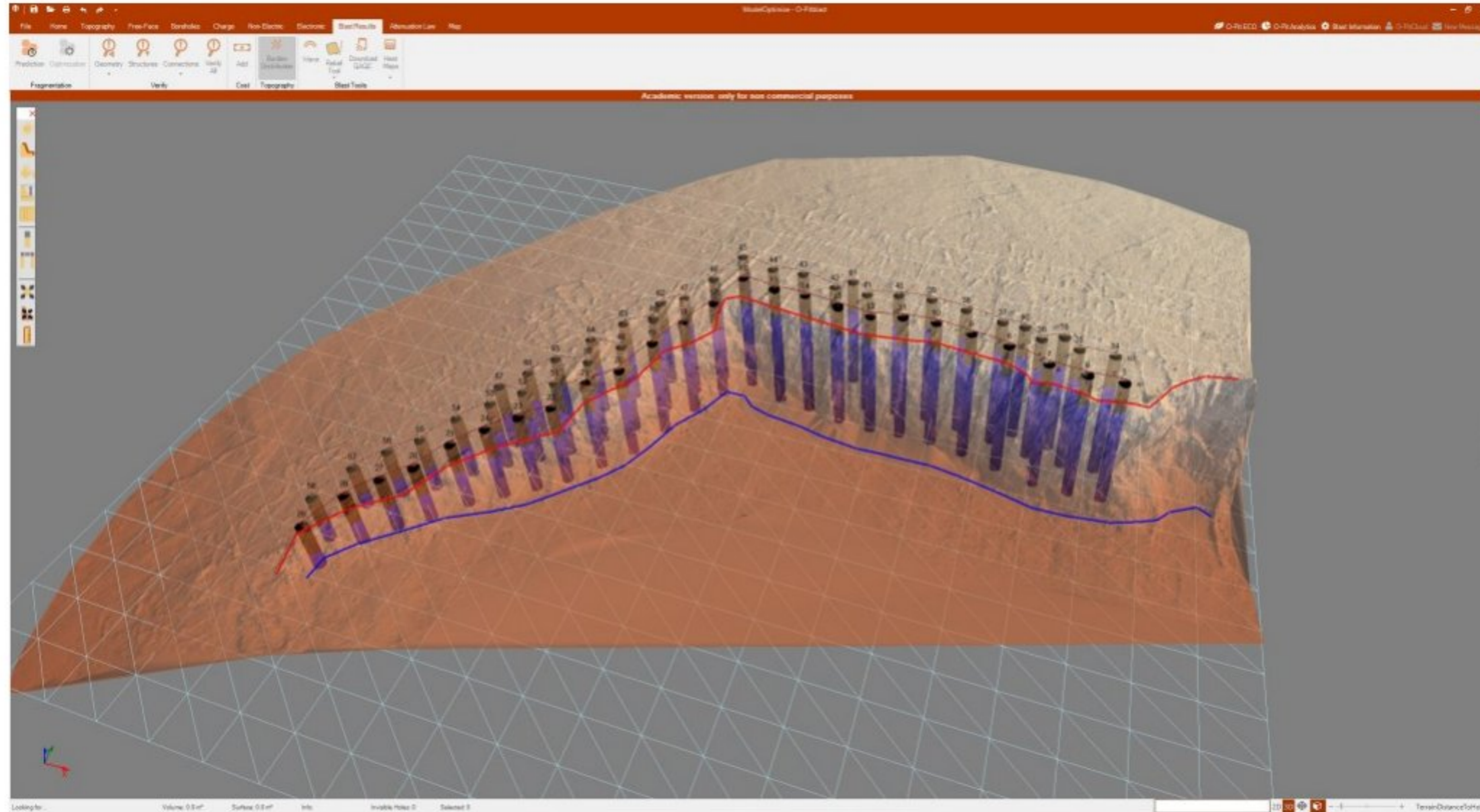


Figure 9 Blast pattern of optimized parameters in the O-Pitblast software

In this case, the subsequent design of the additional blastholes in the first row was not performed, but the software gave us an optimized first row of blastholes according to the model of the level and slope that we entered from the field surveys. This method prevents flyrock because by subsequently drilling holes in front of the first row, it is difficult to adjust the inclination and there is a possibility of pieces flyrock, where the burden is smaller. The following Figure 10 shows the distribution of zones where the burden is larger and smaller than the designed one, where it can be seen that the software gave better parameters than in the case of the previously designed blastfield.

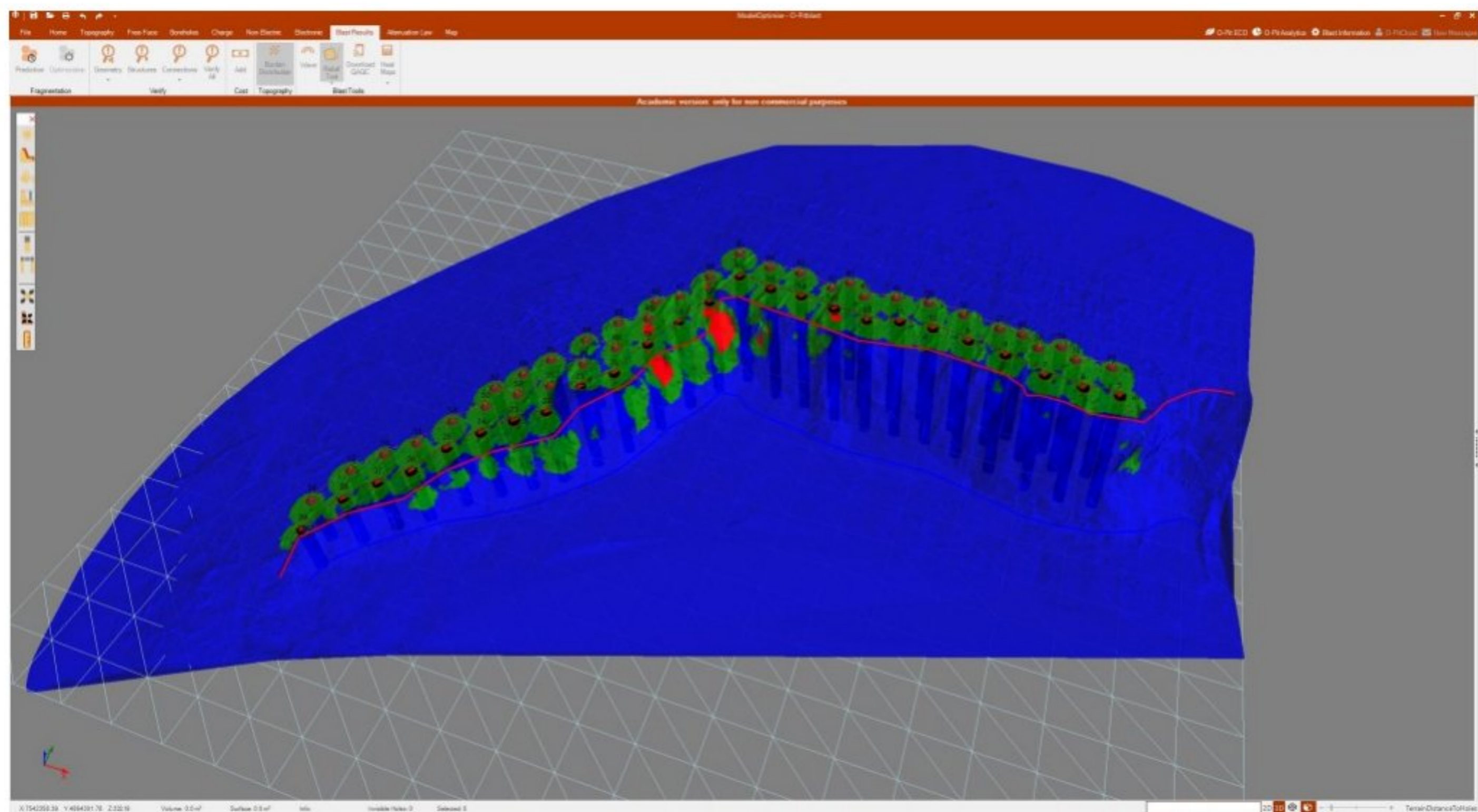


Figure 10 Burden distribution with optimized parameters in the O-Pitblast software

In the case of the designed parameters and zones, the distribution can be seen where the burden is smaller than the given one, which is indicated by the red zone, which represents the zone of possible flyrock, shown in Figure 6. In Figure 10, with the optimized parameters, that zone is reduced to a minimum. As a result of the optimization, a re-evaluation of the fragmentation size of Figure 11 was made, which shows the difference in the designed parameters from Figure 7. The parameters resulting from the optimization are shown in the following Table 3.

Table 3 Optimized drilling and blasting parameters

Parameters	Value
Burden	2.9 m
Spacing	3.3 m
Inclination of borehole	75 ⁰
Stemming	3 m
Bench height	8.5 m
Drilled length	606.5 m
Design volume	4,662 m ³
Number of holes	59

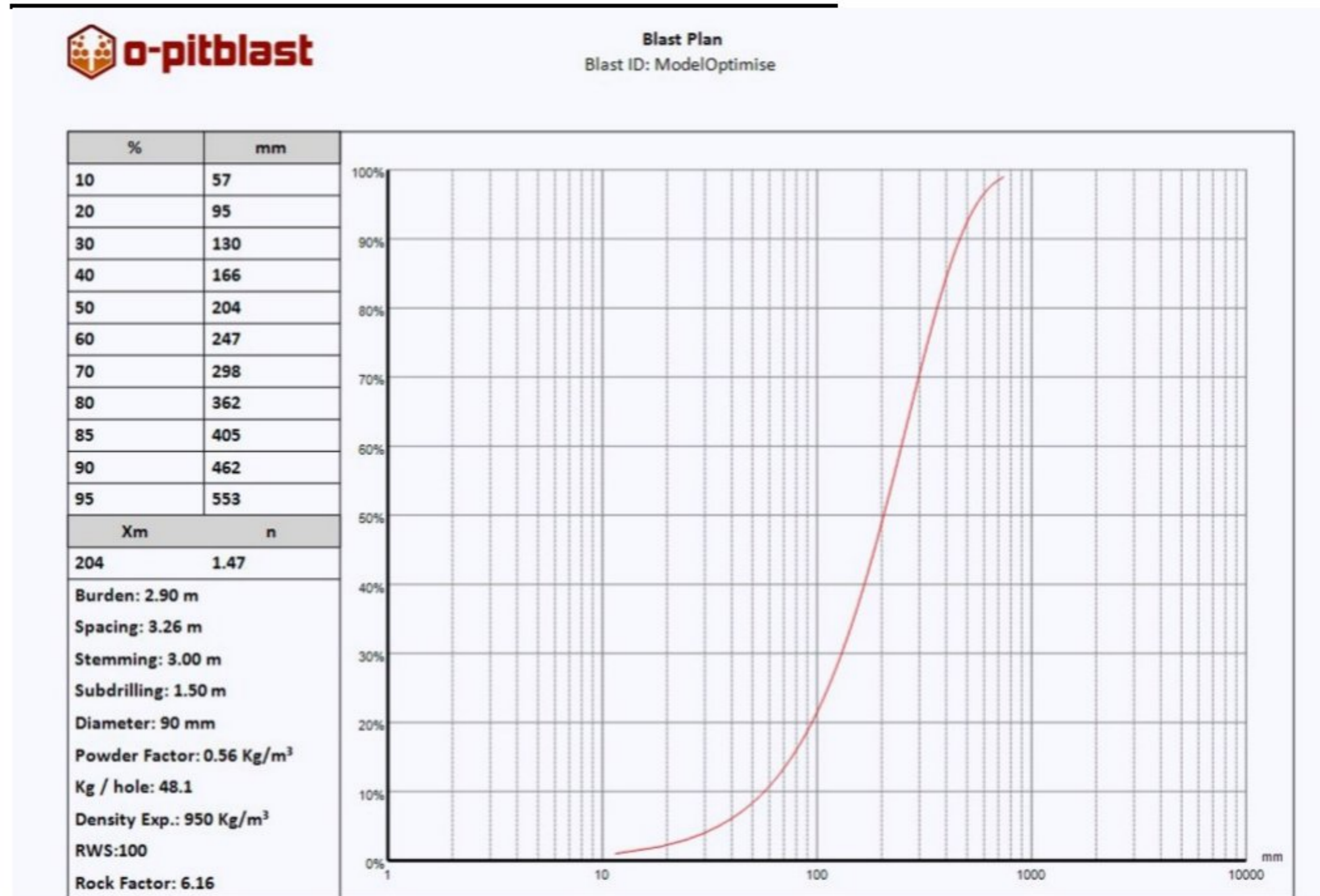


Figure 11 Fragmentation size from optimized parameters in the O-Pitblast software

5 RESULTS OF COMPARISON BETWEEN DESIGNED AND OPTIMIZED PARAMETERS

The difference between the designed parameters of drilling and blasting compared to the optimized ones is represented by the graphic shown in the following Figure 12, where both curves of fragmentation are entered, to compare the results. A comparative analysis between these parameters shows that the average fragment size is better in the case of optimized parameters by 10.2% compared to the designed blasting parameters. In the case of optimized parameters, the drilling geometry has been corrected, while the angle of the blastholes is the same.

A significant difference between these parameters is also observed by comparing the display of the free surface, i.e. the front of the slope with the value zones of the burden size, where it can be seen that in the first case, there are zones of possible flyrock, which is not the case with the optimized parameters. It can also be seen from the analysis that in the case of optimized parameters, the volume of blasted rock material increases, for a smaller number of blasthole, which also reduces drilling costs.

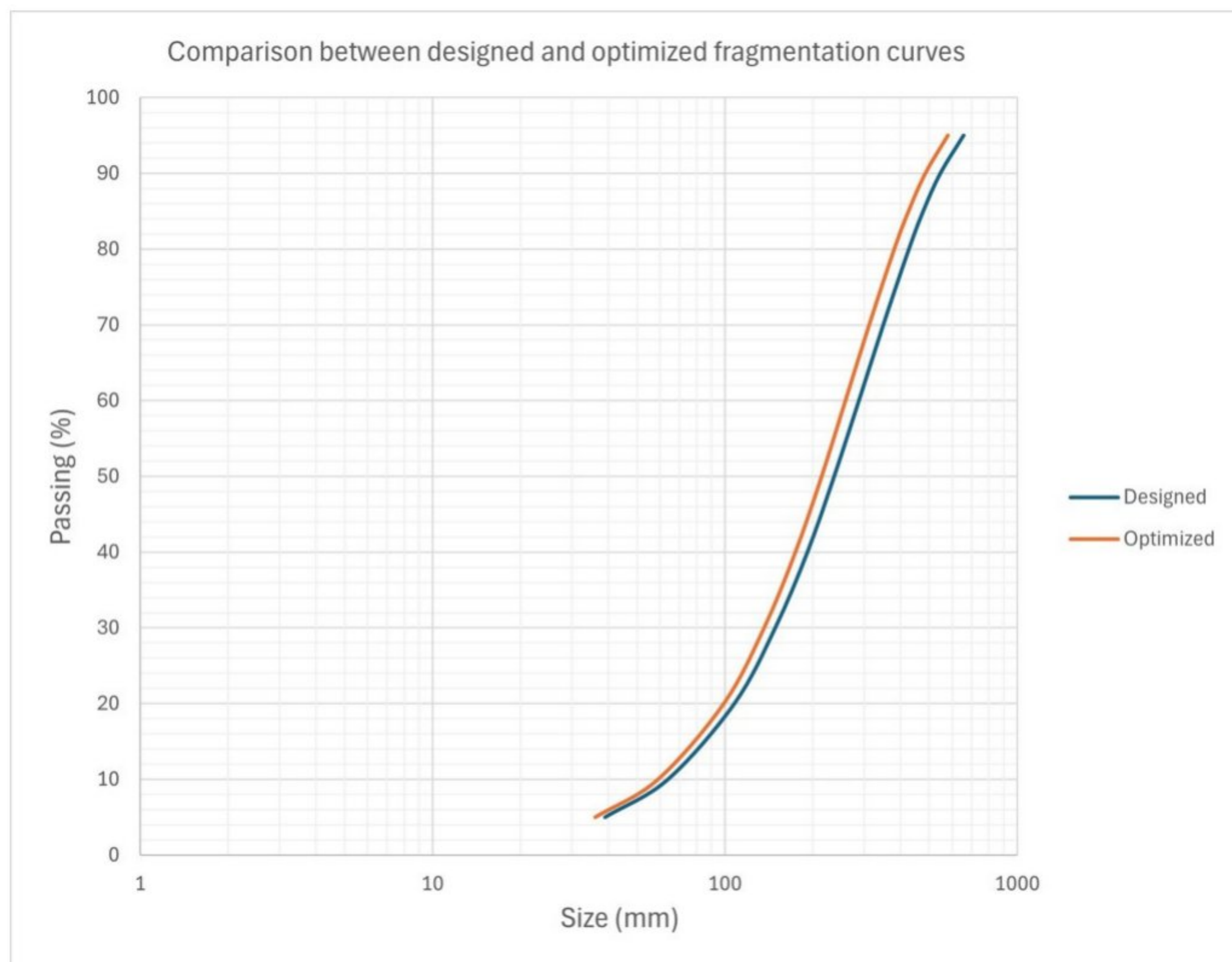


Figure 12 Comparison between designed and optimized fragmentation curves

In addition to the comparative analysis of the granulometric curve for the designed and optimized parameters, a comparison of other parameters such as the volume of blasted material and drilling length was also performed, where the differences are represented by the graphic in the following Figure 13, which clearly shows the difference between the deviation of the values of the designed (blue color) and optimized parameters (orange color). The volume of blasted material is 5.7% higher with the designed parameters compared to the optimized ones, but the drilling length is reduced with the optimized parameters by 12.2% compared to the designed ones.

The parameters optimized in this way ensure a better fragmentation of rock material, with a reduced drilling length (affecting also the reduction of drilling costs), for the small difference between the volume of the blasted material. In the next figure, we can see the difference between optimized and designed parameters which were analyzed through this paper.

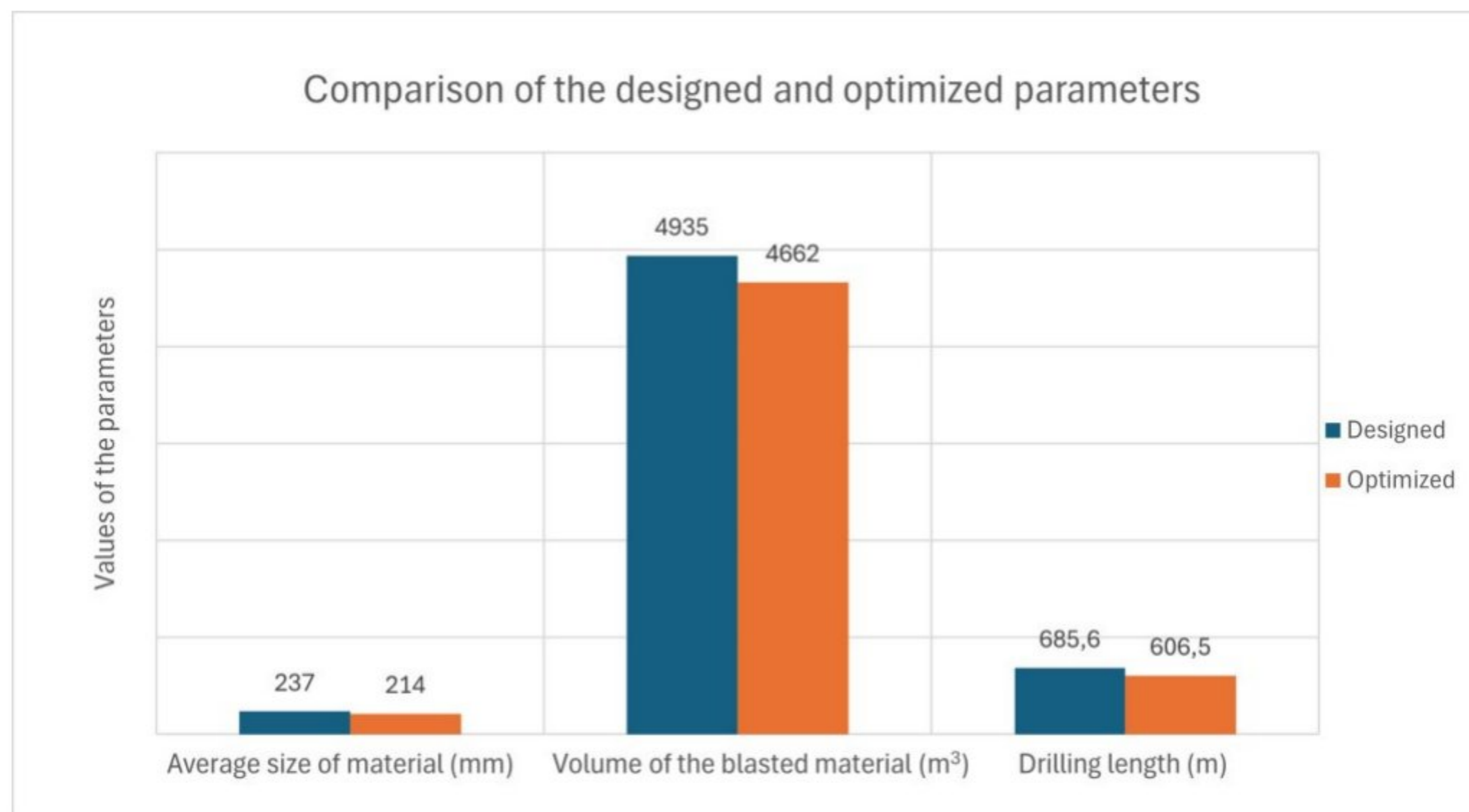


Figure 13 Comparison between designed and optimized parameters

6 CONCLUSION

By the obtained results, it can be established that the fragment size distribution curve is better in the case after the optimization of the drilling and blasting parameters through the software, in this case, the difference is also presented graphically, where can see the exact comparison of the designed results and the parameters after the optimization. First of all, the use of the software enables us to have a detailed overview of all segments from the beginning of the drilling plan to the final part of blasting and the very results that have been achieved.

In addition to the comparative analysis of the fragmentation as shown in the paper and the correction of the first order of drilling to prevent pieces from flyrock, the software enables several additional analyses to monitor blast vibration and develop the attenuation law and similar solutions. So, there are many tools in the software itself to help prevent the side effects of blasting as well as improve blasting results.

With the appearance of this software such as O-Pitblast, the control of the drilling itself has been facilitated, that is, the possibility of designing blastholes according to a real 3D model from the field and the condition of the slope, which enables the borehole to be designed with the exact burden size. By correcting the position of the blastholes, an accurate georeferenced drilling plan is obtained, which is easier to use in the field, and thus improves the quality of blasting and the results in terms of material fragmentation.

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