Rock fragmentation process (Part 02 of 03)

By Bruno Pimentel.

Hello my friends, I hope everyone is well and with good expectations for the month that begins, so as always we leave here the links so that you can check our previous articles, as well as register, so that you are automatically notified of each new one. article we publish. But before that, just reinforcing what we said at the beginning of our last article, due to other demands, we will be publishing our publications monthly.

Português

https://www.linkedin.com/newsletters/desmonte-de-rocha-c-explosivo-6941709482355748864/

English

https://www.linkedin.com/newsletters/rock-blasting-6959820770344595456/

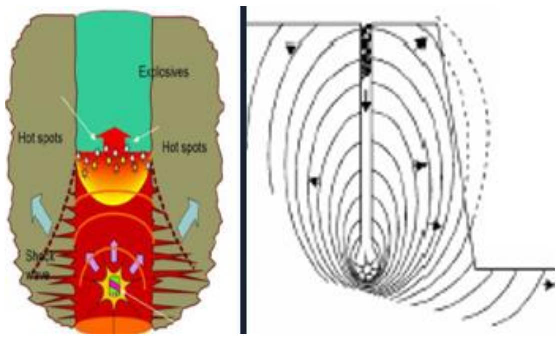
In today's article, we will detail the four main phases of the fragmentation process that we mentioned in the previous article, so that we can have a better understanding of what happens in each phase and how they interact with each other.

PHASE 01 - IMMEDIATE EFFECTS OF DETONATION => SHOCK WAVE

When the explosive detonates, it generates a shock wave, which causes a direct impact on the rock, this impact is caused by the rapid transformation of explosives into gases, releasing a large amount of energy, in the form of pressure and heat.

In our case, when we talk about rock blasting, this impact will be caused directly on the rock that is on the inside walls of the hole, which is the part that is in direct contact with the explosive.

When the shock wave impacts the walls of the hole, they cause a compression force, causing the wall of the hole to stretch, that is, it causes an elastic deformation in the rock, and until the point that the intensity of this wave overcomes the resistance the compression of the rock, and when this occurs, it causes a crushing of the rock.



The extent of this first impact of the explosive's energy on the rock will depend on a number of factors, starting with the rock's properties, ranging from its resistance to compression, to its physical characteristics in the areas close to the hole.

Another determining factor is the characteristics of the explosive, its detonation pressure, as well as the speed of the detonation reaction, which will directly influence the intensity of the impact generated.

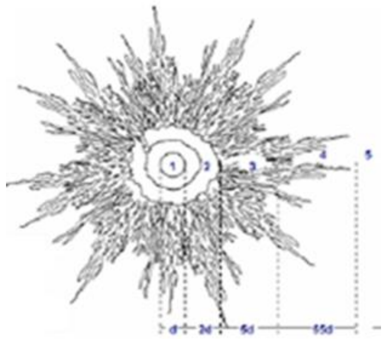
We will also have influences from the configurations of our detonation, mainly from the degree of contact between the explosive and the part of the hole, which we normally relate to the coupling factor of the explosive charge, confinement, and the presence of contaminants in the explosive, and between the explosive and the hole wall, such as water, debris, and so on. And here we see the importance of quality control, both with regard to the quality of the explosive used, and with regard to the conditions of application of this explosive in our detonation.

Also, when we analyze this phase 01 of the fragmentation process, consider that we can have 3 main stages of fragmentation, caused by this initial impact of the detonation on the rock that is on the walls surrounding the explosive:

1 - The first stage refers to the portion of rock that is extremely close to the explosive, normally considering up to a distance of 1 to 2 times the diameter of the hole, and which would be the pulverizing stage, where the rock suffers such an intense impact that it is completely crushed, this being the main portion of fines generated by blasting.

2 - Then we would have the second stage, which normally comprises the rock that is two to five times the diameter of the hole, where we would have the zone of intense generation of cracks, which would be responsible for the generation of fines and small fragments.

3 - Finally, we have the third stage, which is exercised on the rock that is at a distance greater than 5 times the diameter of the hole, until the region that is impacted by the residual force of this initial shock wave of the reaction of the explosive, which occurs in what we call the zone of elastic deformation.



In this zone of elastic deformation, the initial shock wave no longer has the strength to exert consistent fragmentation in the rock, so its effect in this zone runs the risk of being more harmful than beneficial, as it can simply compromise the stability of the formations geological features of the rock, expanding these structures, or simply opening larger fractures, which will cause greater dissipation of gases, thus reducing the pressure generated by them at the time of their expansion.

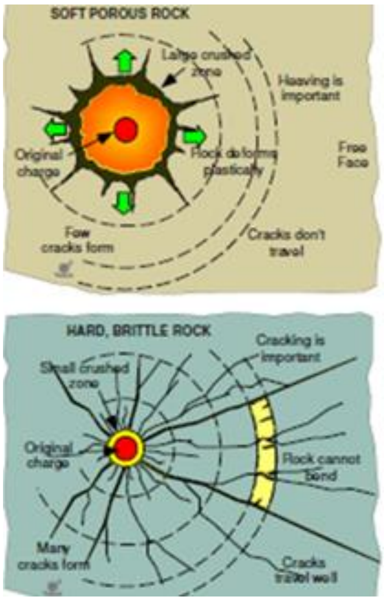
That is why, ideally, we want the first two stages to be more intense, especially in hard rocks, while the third stage is reduced, so that it does not compromise the work of gaseous expansion that will come after this first stage of the process.

A first observation we need to make about this process is that if we had a perfectly homogeneous rock, radial fractures would be created uniformly in all directions, but this does not occur due to the dynamics of rock properties.

Another characteristic of the rock that interferes in this process is its hardness, mainly its resistance to compression, so in hard rocks the first stage, which is the crushing zone of the rock, tends to be smaller, but it has a zone of greater cracking, due to its lower elasticity, so most of this initial energy is used to create and extend the radial cracks.

On the other hand, in soft and porous rocks, which have low compressive strength, we will have a great crushing around the walls of the holes, while we will have a smaller generation of cracks afterwards, due to the greater elasticity of the rock, which causes a great part of of that initial energy is expended to deform and enlarge the walls of the hole.

Here on the side we have a figure that illustrates this well, where at the top we see a soft rock, which undergoes a large enlargement of the walls of the hole, due to its greater elasticity, while at the bottom we see a hard rock, which suffers many radial fractures, which will be very intense close to the hole and will decrease as you move away from it.

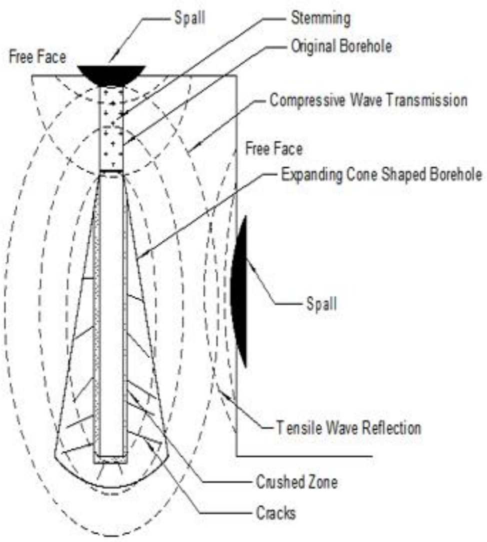


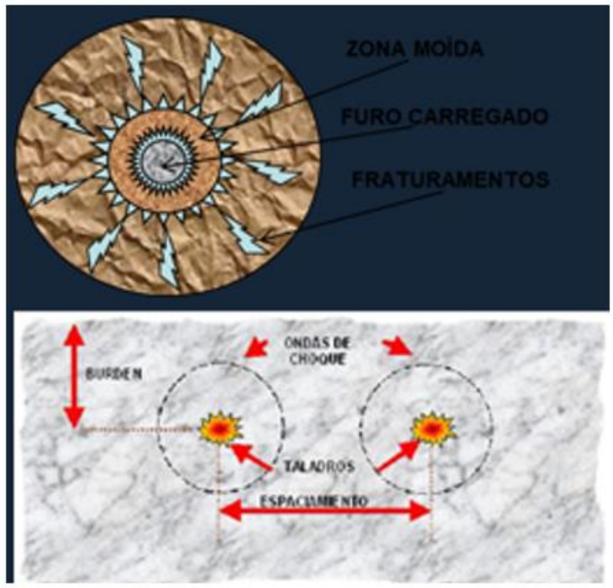
Later on, we will see that in hard rocks, the gases generated will penetrate these fractures, and any other discontinuity present in the rock, and will force these fractures to extend, increasing the level of fragmentation. Thus, the greater the number of fractures generated initially, the greater the level of final fragmentation generated in this process, influencing mainly the portion of intermediate fragments in our material.

The first fragmentation zone, in the region surrounding the hole, is responsible for most of the fine material produced by the blast, but it represents a very small portion of the rock, so when the objective of fragmentation is to seek a greater amount of fines, it is necessary to maximize this zone as much as possible during the blast, looking for explosives that generate a greater initial shock wave, and also using a greater number of holes.

We consider that the first phase ends when this initial shock wave loses its intensity, down to values smaller than the elastic limit of rock deformation, that is, smaller than its compressive strength, as this wave is no longer able to further break up the rock.

Even without being able to fragment, the shock wave continues to travel through the rock, and when it encounters a fracture or discontinuity, it creates tangential tensions that can create new cracks.

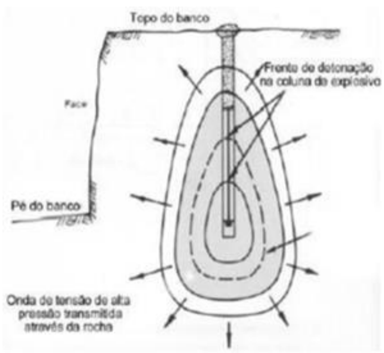




When the shock wave arrives at the free face, it is reflected on this surface, returning to the interior of the rock, and now making an opposite pressure effort, in front of the waves that continue to compress the rock, it generates traction and shear forces in the rock , which normally has a much lower resistance to this type of effort, and so we begin our second phase of the fragmentation process.

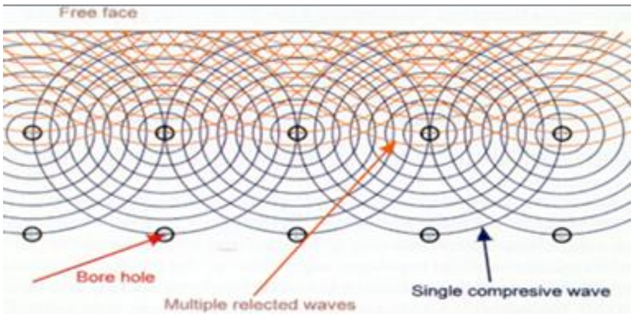
<u>PHASE 02 - SHOCK WAVE PROPAGATION IN THE ROCK</u>

It is considered that the beginning of the second phase occurs with the propagation of the shock wave along the rock, which now no longer exceeds the rock's compressive strength, but continues to compress it until it finds the free face, where we have an interface earth-air, and so it is reflected on this surface returning in the opposite direction, which causes it to create an opposite pressure, generating a traction effort, which creates cracks as it passes, and even widening the natural weakness planes of the rock .



This happens because the rock's resistance to traction is much smaller than its resistance to compression, so that the wave that did not have the strength to break the rock by compression, when reflected, manages to come back breaking the rock again by an effort of traction.

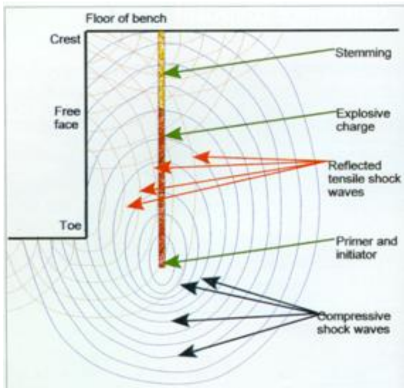
As we see here in the illustration below, the blue waves represent the shock waves coming out of the hole, and which cause the compression stress, but as they are reflected in the free face, which we have here in red, they come back opposing the compression waves, thus causing a tensile stress that is able to continue fragmenting the rock.



Normally, it is considered that in this second phase we have the highest percentage of rock fracturing, and that together with the effort generated by the expansion of gases, they are responsible for the largest share of rock fragmentation.

For this reason, we always talk about the importance of the free face and the generation of relief along the blast, as they are responsible for the reflection of the waves that act on the largest fragmentation portion of our rock, and this occurs with all types of blasts, both in open pit or underground.

This second phase is based mainly on the theory of wave reflection, which was one of the first theories proposed to explain how rock breaks when we blast a hole close to a free face.



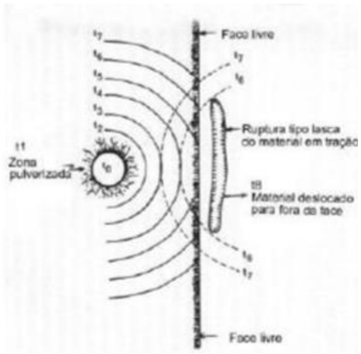
This theory indicates that as the compression waves propagate they lose strength, and thus need a free face so that they can be reflected back, and thus manage to generate an effort contrary to the compression waves, pulling the rock and continuing the fragmentation process.

Consider that, approximately, the tensile strength of rocks is 10 to 15 times lower than their compressive strength, and therefore the effort generated by the reflected waves can cause much more intense fracturing than that generated by the waves initially .

Another important detail is the blast speed of explosives, because the higher this speed, the more intense and faster the waves are, and thus they propagate and reflect more intensely, increasing the interaction between the various waves, which causes us to have an increase in fragmentation in this second phase of the process.

In addition to the interaction process between the waves, we have another phenomenon that occurs during the reflection of waves on the free face, which is precisely caused by the result of the reflected and refracted waves on the free face, which we call face peeling or “spalling”.

As we see here in our illustrations, as the shock waves meet the free face, tension is generated at that point, which is precisely the action between the reflection and refraction of the waves, causing the displacement of portions of the rock.



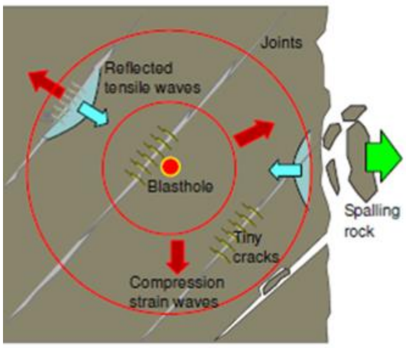
This phenomenon is even more intense when we have a spacing smaller than the ideal and a higher load ratio, as we will have a large accumulation of waves, with greater intensities, at the rock-air interface.

As soon as we realize that the spacing also plays a fundamental role in the fragmentation process, and therefore it needs to be well dimensioned, because when we have a spacing smaller than the ideal, we can have two situations that will interfere in the fragmentation process, where the first, that with a very small spacing, the compression waves themselves can have excess force to start moving the rock, without having completed the fragmentation process, and second, that the spalling process, or “spalling”, increases considerably , mainly in rocks that are more fractured, or that have damage on the free face.

When we have the opposite case, with a distance much greater than the ideal, the shock waves will have to travel a long way until they find the free face, losing intensity, and thus when they are reflected, they will have a very low force, reducing fragmentation.

Therefore, we can say that the ideal spacing will prevent the rock from being moved ahead of time, reduce the effect of “spalling”, and cause the waves to reflect, as soon as they finish their effect of rupture by compression, returning as intensely as possible, like waves of traction.

Another important observation is that during the propagation of shock waves in the rock, they can find discontinuities and open structures in the rock, which will act as a small free face, and thus part of the waves will be reflected and refracted on this surface, and even if with lesser intensity, this feat will also generate traction waves, which in this case will mainly widen these structures, opening them in a more intense way.



This has two sides, on the one hand, it contributes to the application of fractures and the creation of new fractures, helping in the fragmentation process, but on the other hand, if these fractures are very representative and with large extensions, many waves will be reflected in them, opening them up. as, and this can cause the gases, which are starting to penetrate the fractures, to find exits from the rock, losing intensity.

That is why when we look at the reflection of the waves, one of the most important factors is the presence of “free faces”, as they will directly interfere with the final result of the rock fragmentation process. Thus, a good part of our fragmentation will be determined according to the amount of "existing free face", its nature, orientation, distance from the explosive charge, and its different properties.

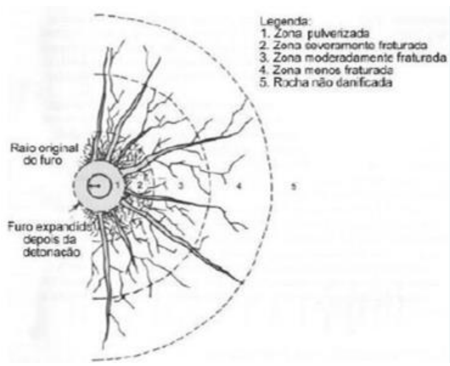
We need to understand that the "free faces", or the interfaces existing in the rock, will determine the direction and interaction between the waves, which can significantly contribute to the process, or hinder the process, depending on its characteristics. Therefore, the process of rock fragmentation with intense fracturing is much more complex, because the various discontinuities will interfere with the interaction between waves, and will even contribute to the dissemination and loss of intensity of gaseous expansion.

PHASE 03 - BLAST GAS EXPANSION

When the explosive detonates, in addition to releasing the shock wave, it starts together, the decomposition of its components, and their transformation into a large amount of gases, so that we have practically simultaneously with the previous phases, the beginning of the 3, where its effect on the rock occurs with a delay of a few milliseconds in relation to the previous phases, but in its continuity they occur in a complementary way.

In phase 3, the expanding gases penetrate the cracks created by the shock waves, widening these cracks, and creating new cracks, thus producing effective rock fragmentation.

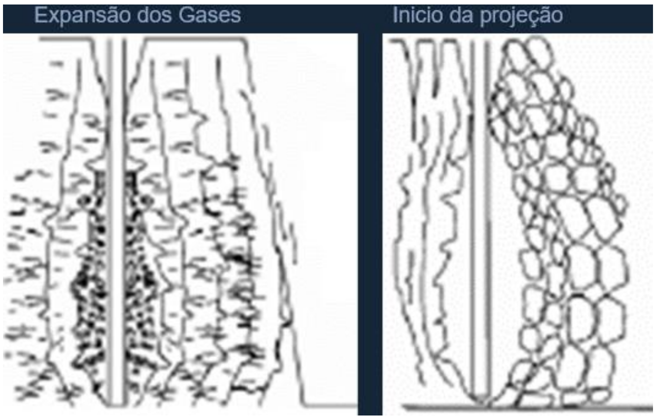
This process, despite occurring in sequence, its action is simultaneous, because while the fractures are being created, the gases are already expanding and penetrating these fractures, widening them and creating new fractures, which causes the action of shock waves to and the expansion of gases, are mainly responsible for determining the final fragmentation of the rock.



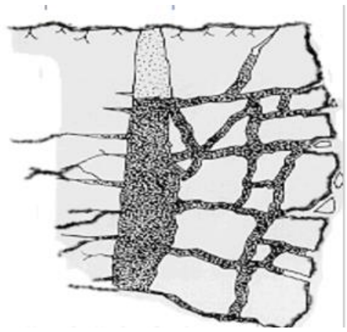
During this process, the gases continue expanding, increasing the pressure generated by this expansion, forcing the rock towards the free face, until they reach their maximum expansion, and thus causing a great bending in the rock, and when it exceeds its limit, the gases break through the rock completely, and are dispersed into the atmosphere.

A point of attention in this third phase is that there is a lot of contestation and conflict between the different concepts and theories proposed, especially with regard to the fragmentation process during this phase.

Some theories will indicate that the network of fractures has already been created by the interactions of shock waves, and that the gases will only widen these fractures and release the material. On the opposite side, we have those who indicate that the shock waves only crush the rock around the hole, and only generate some weaknesses in the rock as it passes, so it would be the gases responsible for carrying out the intense fragmentation of the rock, and this process would start effectively in this third phase. But eliminating these two extremes, even though there is much divergence of how it occurs and what actually happens in this third phase, most theories will indicate a complementary process between the action of shock waves and the expansion of gases, these two being the main responsible for the generation of rock fragmentation.



Following this reasoning, we have that the effect caused by the gases in the rock, is generated by the pressure that the gases exert on the walls of the hole during the blast of the explosives, and this pressure generated by the gases will be related to the total volume of gases and the great increase the temperature of these gases.



An important point to keep in mind is that the pressure generated by the gases in the rock is not the same pressure generated by the shock wave of the explosive, as the pressure of the explosives generates a punctual peak, while the pressure of the gases is continuous. , during its expansion, increasing its intensity, until it breaks the rock or finds an escape point. This pressure generated by the gases will have a lower intensity than the peak generated by the shock wave, but it still has a fundamental effect on the rock fragmentation process.

We usually call the pressure of the shock wave, blast pressure, while the pressure caused by the expansion of gases, we call blast pressure or pressure in the hole.

It is important to bear in mind that all of this occurs over a very long period of time, and if the parameters of our blast plan are correctly dimensioned, and are well executed, the gases, in addition to working together with the shock waves in rock fragmentation, will expand to the point of breaking the rock, after its intense fracturing, throwing it towards the free face

In summary, to understand the process of action of gases, we can follow these steps:

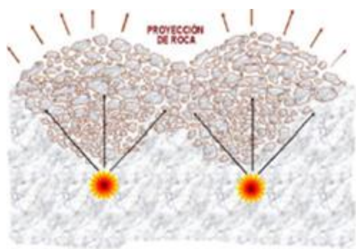
- • Firstly, when the explosive starts its blast, the volume of the hole that was filled by the explosive will be quickly filled by a large volume of gases, in great expansion and at a very high temperature.
- • As soon as the gases completely fill the hole, they continue to expand, filling the cracks, which were created by the shock wave, and as they continue to expand, they generate pressure, opening these cracks more and generating new cracks.

- • As the gases continue to expand, they exert a very high pressure on the rock, on the wall of the hole and on the fissures, causing all the rock to flex, expand, and thus be thrown towards the free face, as we can see see the example of that moment, in the photo here in the lower right corner.
- • During this movement of the rock, the different pressures suffered at each point, the difference in rock movement and speed, cause it to suffer shear at some points, which also contributes to a small portion of fragmentation at that time.
- • Finally, as the rock fragments are launched, they collide in the air, and also collide when they fall to the ground, this being the last phase of our fragmentation process.

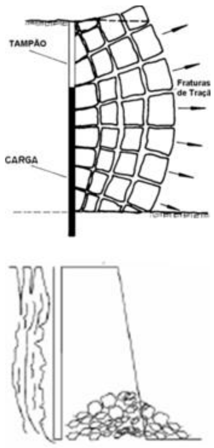
PHASE 04 - DISPLACEMENT OF MATERIAL

In the final phase of the fragmentation process, the largest portion of rock fragmentation will have already been defined, and at that moment, we have the final action of the gases, breaking the rock and throwing it towards the free face.

In phase 4, if the displacement is correctly calculated, the shock waves have already created as many cracks as possible, the gases have already expanded these cracks and flexed the rock as much as possible, to the point that the rock mass breaks, and at that moment, we have the use of the residual force of the gases to move the rock forward, until the gases disperse, and the rock fragments will fall due to the force of gravity.



During this process, the complement of fragmentation takes place in three ways, where first the pressure difference at each point of the rock and the difference in the moment of rupture between the different points, causes shear to be generated between the different portions of the rock. , increasing its fragmentation. Then, as they are launched, the fragments collide while still in the air, causing another fragmentation portion, and finally, as they fall, the fragments collide with the ground and with the others, and thus we finish the fragmentation process in phase 4 , which actually represents a small portion, and has a greater effect on larger-sized fragments.



Practically this is the only stage that occurs alone, and it starts after the others finish, although, if we have points of weakness in the rock, it may be that part of it has already entered this phase, while other parts are still suffering the effect. of the previous stages, but when we have a good development of the process, it will start with the finalization of the previous stages of the process.

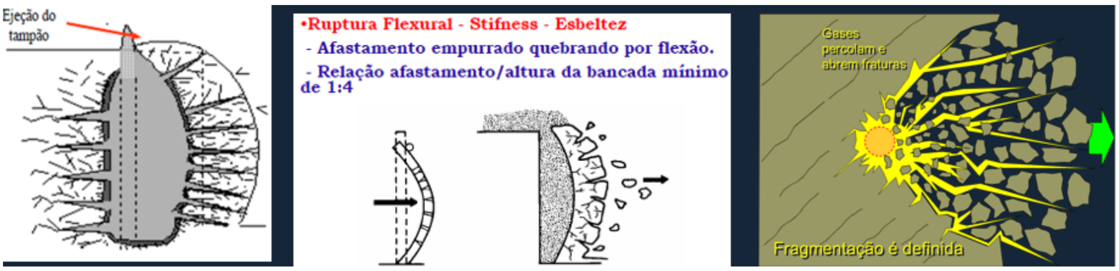
An important point is that it is the degree of confinement of the explosive, inside the hole, which will define the time of the other stages, until we reach this final stage. So, the more the gases are confined inside the rock, the more they will act in the previous stages, increasing the pressure and the degree of fragmentation on the rock, before it starts the process of rupture and release of the material, towards the free face.

Here, the parameters of the fire plane have a fundamental effect, mainly the stemming, the load configuration and the spacing, since they are the ones that will interfere the most with the confinement, during the blast process.

As the gases escape, they begin to project the fragments that are in contact with them, and which are already loose, thus reducing the pressure exerted on the rest of the rock mass.

When the gases find a point of escape, we have two opposite effects, first the risk of launching loose fragments, at great distances, due to the greater pressure of the gases, and thus we have the risk of flyrock events, or the escape of the gases, will cause a decrease in the pressure exerted on the rock, reducing the effect on fragmentation and on the release of material.

Thus, for all phases to act in such a way as to deliver the best result, it is necessary that the parameters of the fire plan are well dimensioned, and that the rock, be as compact as possible, without weak points, which will interfere during the process.



That's it folks, it's important to understand each process and the interrelationship they have with each other, but for today we'll stop here and in our next article we'll continue commenting on the main points that can impact the fragmentation process and thus the final result of the our dismantling.

As always, we ask that you please comment and share, so that we have safer and quality detonations!!!

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