Hiding Powder is not as Simple as it Seems

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Introduction

Blasting complaints are one of the most common issues industry technical consultants are hired to evaluate. When considering the facts surrounding blasting complaints, especially when damage is alleged, we are constantly balancing between considering the details of the complaint, often as emotionally related by the person or persons affected, while at the same time working alongside industry professionals who, for the most part, faithfully perform their work with high regard for public safety and government regulations.

When a blasting complaint is made, it is the responsibility of the person investigating the complaint to conduct a thorough, impartial, and unbiased investigation into the incident or allegations, and then to produce an equally thorough and unbiased report detailing his or her findings, and if warranted offering recommendations. The elements of any such investigation may include reviewing blasting records, seismic monitoring reports, interviewing onsite personnel and witnesses, conducting research, conducting seismic monitoring of blasting activities, and compiling data into a useable and understandable format.

Of all the elements in evaluating an incident or allegation, the most unpredictable and certainly one of the most interesting can be the complainant interview. And of all the accusations we hear, one of the most common is that the blasting contractor is getting away with using more explosives than they are reporting, thereby shaking the complainant's home harder than we think they are. The assumption is usually based on the belief that mine operators and blasting contractors would benefit from using more explosives in their blasts and concealing the use of the additional powder.

As unlikely as the scenario may be, this article examines whether or not it is possible for a blaster or blasting contractor to effectively use and conceal greater quantities of explosives than they report. We will look at possible means by which a contractor could use more explosives than they are reporting, whether or not that could be reasonably concealed from an investigator (and if so to what extent), the potential consequences of using and concealing more explosives than they are reporting in a blasting operation, and the risks versus rewards of doing so.

For the purposes of this article, we will be looking only at possible means of using greater than reported quantities of *bulk explosives* in a typical stone quarry blasting operation. While it would be relatively easy to conceal the use of a few more cast boosters and detonators than reported, the effect of such a small quantity of explosives (only a few pounds) in combination with thousands of pounds of bulk-loaded explosives is negligible. For simplicity's sake, we will assume that we are considering a limestone quarry operation blasting under the following parameters:

- Bench height: 50 ft
- Hole depth: 53 ft
- Average powder column length: 43 ft
- Number of rows deep: 5
- Number of holes long: 15
- Total number of holes: 75
- Average hole diameter: 5.5 inch
- Distance to nearest unowned structure: 1500 ft
- Two types of bulk explosives used
  - ANFO at 0.82 g/cc density
  - Emulsion at 1.26 g/cc density

For our discussion here, vibration predictions will be based on the industry standard quarry production vibration prediction model:

$$PPV = 52\left(SD^{\frac{1}{2}}\right)^{-1.38}$$

Possible means and consequences of using and concealing the quantity of explosives used in a blasting operation

There are only a few reasonable methods by which a blasting contractor could utilize and conceal more explosives than the given blasting parameters allow:

1) By loading more explosives in boreholes as they would be normally laid out and drilled,
2) By drilling deeper holes to accommodate a longer powder column,
3) By drilling and loading more holes than reported,
4) By altering product densities on paperwork (or by using a heavier product than reported),
5) By increasing hole diameter.

Considering each of these possibilities will allow us to eliminate the options that are the most unlikely, so we can focus on realistic means by which an operator could use and conceal the amount of explosives used in their blasting operations.

Method 1: The easiest way to increase the amount of explosives used in a given blast would be to simply load each hole with more powder than reported by increasing the powder column height. So, if holes are usually loaded to ten feet before stemming, the blaster would load each hole to nine or even eight feet. This option naturally limits the amount of additional explosives that could be utilized to only an additional foot or two of powder for the simple fact that the explosives occupy a specific volume per pound and there is only so much volume of borehole that can be filled while still allowing for an effective amount of stemming to be used. Figure 1 below shows the difference in total quantity of explosives used by increasing hole loads by one and two feet respectively. Figure 2 shows the increase of predicted vibration values as the holes loads increase by an additional one and two feet respectively:

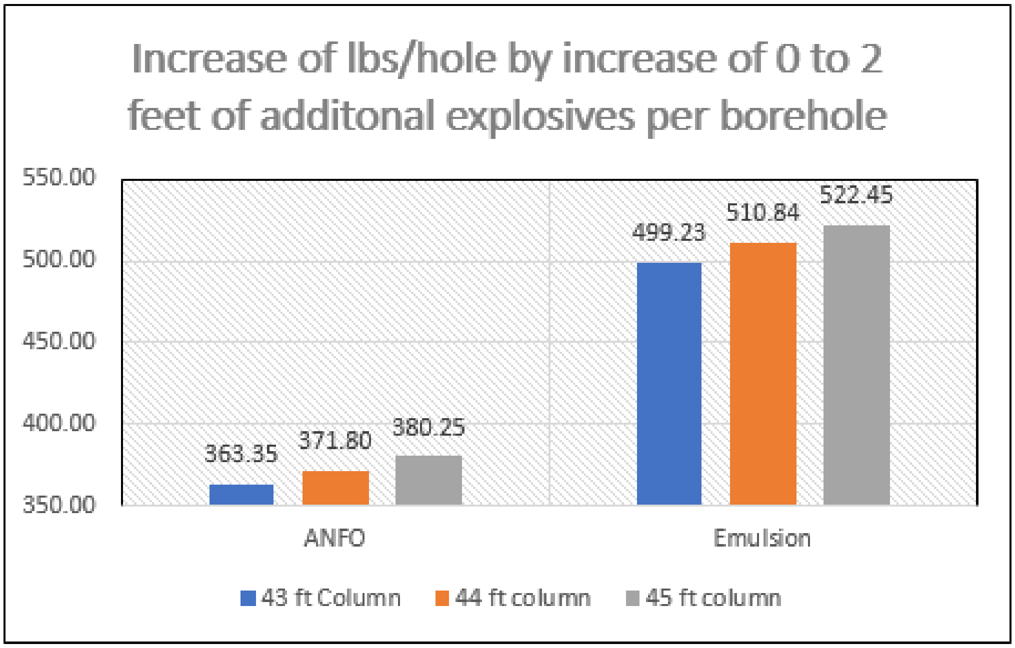

Figure 1

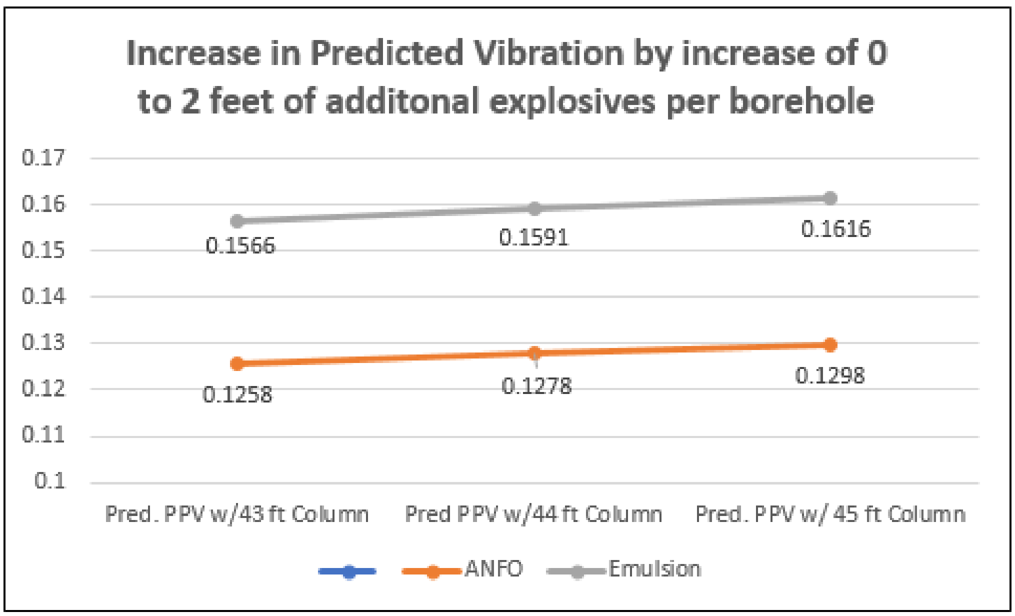

Figure 2

Simply loading a little more in each borehole on a blast that was already drilled would have a negligible effect on the intensity of the vibration expected at the nearest unowned structure at 1500 feet away, assuming we are maintaining one hole per delay < 8ms. The difference in weight per borehole by increasing the powder column by two feet only amounts to a maximum 16.9 lbs. for ANFO, and 23.22

lbs. for emulsion. For a 75-hole shot that equates to 1267.5 lbs. total additional ANFO used across the entire blast, or 1741.5 lbs. additional emulsion. The total weight of explosives used in the entire blast, assuming the given standard loading parameters would be over 27,251 lbs. for ANFO and over 37,442 lbs. for emulsion.

A simple comparison between the total explosives that would be used in such a blast versus the additional weight that would be distributed across the entire shot shows that the increase in weight of explosives would be a small percentage of the overall weight. So, while it would be possible that a few holes could be loaded to one or two feet more than reported, the effects of doing so would be minor. Therefor we can discard loading a little more into each hole as a viable means by which a blasting contractor could conceal the use of enough additional explosives to have a negative impact on surrounding structures.

Method 2: One way to get around not having enough room within a borehole to load more explosives would be to drill the holes deeper than reported. While it is conceivable that someone could determine to do this prior to commencing the drilling of a blast, it is highly unlikely that anyone would do so, simply given ineffectiveness as a technique and the downstream consequences of that action.

When it comes to mining everything is about cost and efficiency. Considering cost alone, drilling and blasting is an expensive part of a mining operation. Drilling is usually included in the overall cost of a blast at a certain price per foot drilled, which can get very expensive. Explosives costs are charged either by the unit, which would reflect directly on customer invoicing, or it is included in the price per ton blasted, which would mean that the blasting contractor would have to accept the loss of additional explosives loaded in a blast. In a world of multi-year contracts where fractions of pennies mean the difference between working and not working, the financial impact of using more explosives than a blasting operation should need would be serious, especially over time.

Considering efficiency alone, which could also be assessed in financial terms, drilling deeper for the purpose of trying to use more explosives would cause far more problems than it would be worth. Drilling deeper means that the floor of the quarry would be crushed by the action of the blast itself. The following year, when that floor became the top of the next bench to be blasted, all of that crushed rock would have to drilled through. The wear and tear sustained by a drill under those conditions is significant, as are the increased safety concerns that arise from loose rock situated around the collar of a borehole. And all of that assumes that the drilling the following year could be done at all without losing the holes due to the collapse of unconsolidated material falling in as the drill string is retracted.

Finally, the effectiveness of trying to achieve a better blast by drilling deeper so one could use more explosives, is unreasonable due to the mechanics of rock blasting. For a blast to be truly efficient in an open pit mining scenario the rock has to be able to move out, or cast, into the pit. If the rock mass is not displaced very much the digging becomes harder, equipment sustains more abuse, efficiency decreases, and costs per ton produced increase.

Therefore, considering these three—cost, efficiency, and the mechanics of rock blasting—method 2 may also be discarded as a viable means by which an operator would use and conceal increased amounts of explosives as a practice in a blasting operation.

Method 3: Another more reasonably considered means by which an operator could attempt to use and conceal more explosives in their blasting operations would be to load and shoot more holes than logged in their post-blast report. On one hand, the increase in total pounds of explosives using the parameters given for our example would be more significant, between approximately 363 lbs. and 499 lbs. per additional hole loaded, using either ANFO or emulsion, respectively. Increasing the size of the blast by only ten holes (two holes per row in a five row blast) would result in an increase in the total pounds of explosives used from approximately 3633 lbs. using ANFO to approximately 4992 lbs. using an emulsion.

However, although the total explosives used could increase quickly by increasing the number of holes in the blast, it would be more difficult to conceal for two reasons. The first reason is that the use of additional holes could show up in the duration of the blast. All of the loaded boreholes in a blast are not fired simultaneously. They are delayed sequentially in milliseconds both in order to limit the amount of explosives detonating at any given time and to create a general direction of relief in which the blaster intends the mass of rock to cast. If the blaster were to connect the additional holes using a consistent timing scheme, the total duration of the blast would increase.

The increase in blast duration would be easily detectable simply by reviewing the blasting seismograph records. Most blasts must be monitored using seismographs designed for that purpose. The blasting seismograph records air overpressure (an energy wave emanating from a blast and passing through the air) and ground vibration (an energy way emanating from a blast and passing through the ground). Each trace, whether vibration or airblast, is recorded along a time scale, as shown in Figure 3. A simple comparison of the length of the recorded trace versus the timing scheme reported by the blaster would show any discrepancy.

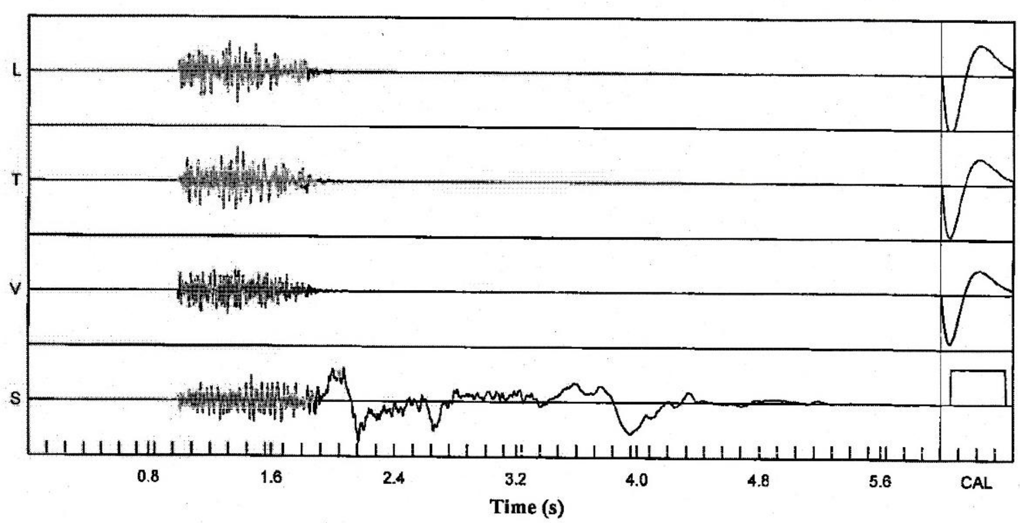

Figure 3

In addition, one of the primary reasons a blaster uses millisecond delays is to try to control the amount of vibration energy that emanates from the blast. He or she will use a timing scheme that attempts to separate the detonation of individual charges throughout the blast by a certain amount, usually no less than eight milliseconds (ms). In most cases, as long as they are separated by eight milliseconds or more, each charge is considered individually with regard to the amount of vibration energy it releases. When the individual charges are properly separated, whether by eight milliseconds or some other effective delay, the intensity of vibration energy moving out from a blast through the ground is reduced. All of this is done by blasters as a normal, everyday practice to protect surrounding homes and businesses from the effects of ground vibration produced by blasting.

If a blasting contractor determined to conceal the use of additional explosives in a blast by drilling more holes, and wanted hide that by keeping the duration of the blast the same as it would have been with the original number of holes, there would likely be overlaps in the timing sequence because the blaster would have to find a way to jam that extra hole into the existing timing sequence. Overlaps in timing would quickly lead to unexplainable increases in vibration levels. Figure 4 shows the increase in pounds of explosives per delay as overlaps increase by one additional hole at a time up to four holes firing simultaneously. Figure 5 shows the increase in predicted vibration levels as the number overlapping delays increases. Since vibration levels increase as charge weight increases, these graphs demonstrate how that relationship would quickly become evident in an investigation if a blasting contractor were to try to conceal the number of holes in a blast by hiding the additional holes within the timing scheme resulting in multiple holes per delay.

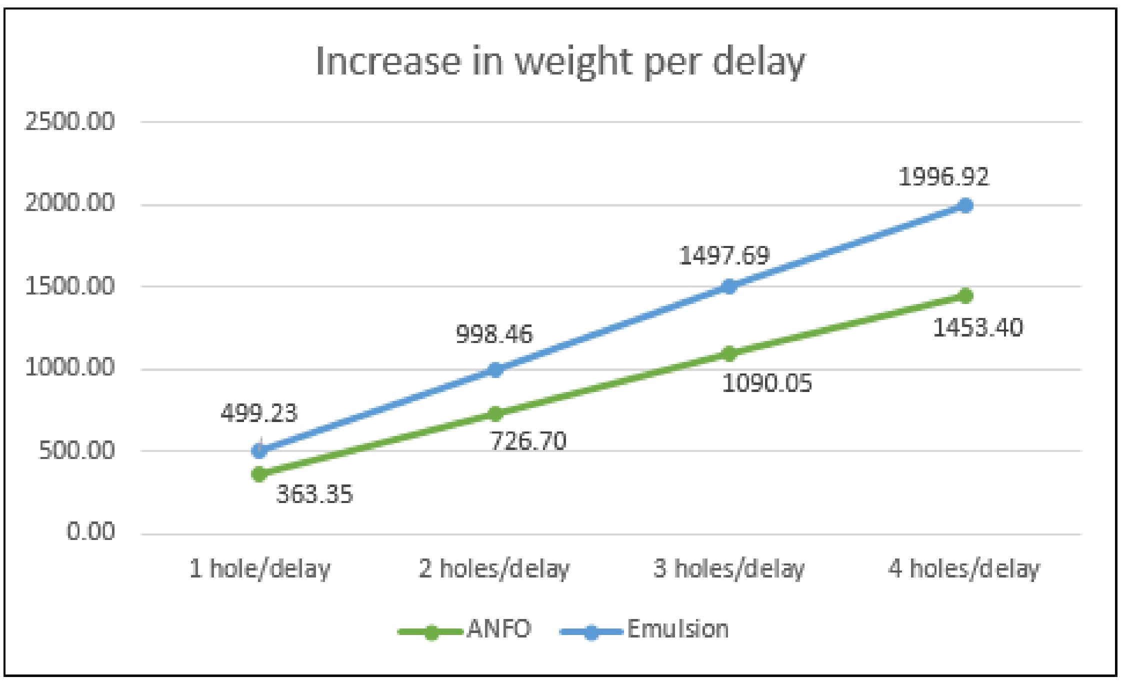

Figure 4

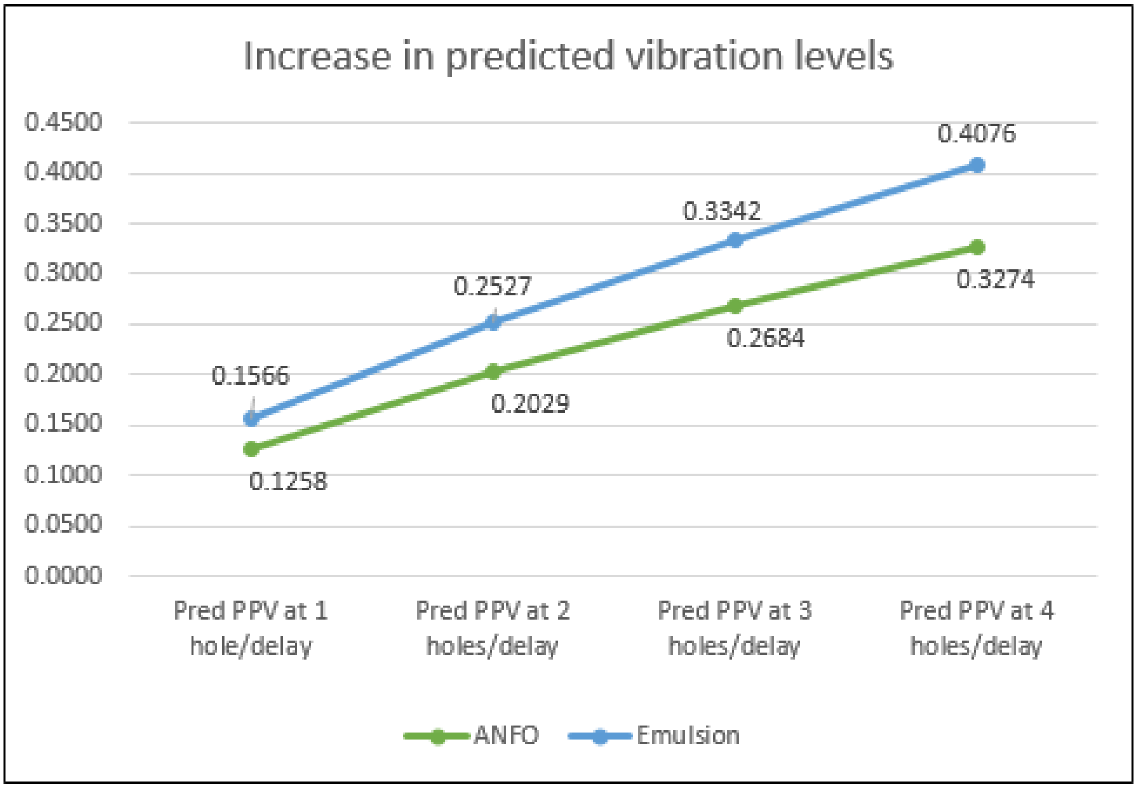

Figure 5

With very careful planning, it is possible that an operator could conceal the fact that an additional few holes were used in a certain blast, but to do so as a practice or in a case where they were trying to hide more than a few additional holes, it would not be reasonable. For this reason, except for a possible rare instance, method 3 of using and concealing the use of more explosives than reported is not considered likely.

Method 4: A forth, possibly more reasonable method by which an operator could use more explosives than reported would be to alter the reported density of the products they are using on their post-blast report, or by using a heavier product than they reported, such as reporting that they used ANFO versus an emulsion type explosive.

One of the key factors that describes an explosive product is its product density. Density is almost always thought of as the mass of certain volume of a product in comparison to the mass of the same volume of water. So, if we had a quarter cup of water whose mass was measured at 358 grams, and a quarter cup of emulsified explosives whose mass was 449 grams, we would be able to calculate the density of the emulsion as follows:

$$D = \frac{449}{358} = 1.25\ g/cc$$

For emulsified explosives, a product density of 1.25 grams/cubic centimeter (g/cc) is within the normal range of what one would expect for that kind of product. We can say that because in looking at industry standard explosives, we see that products usually fall within a certain range of product densities. For example, an emulsified explosive would have a typical product density averaging somewhere around 1.25 g/cc, where as ANFO would have a product density somewhere around 0.83 g/cc. This changes the weight per foot loaded dramatically. Using the following equation to determine the pounds of explosives per foot of borehole, where 0.3405 is a constant,

$$Weight = Hole\ diamter^2 * \ 0.3405 * density$$

we find that ANFO with a density of 0.83 g/cc loads at 7.65 lbs./ft in a 5.5" diameter borehole, where as an emulsion with a density of 1.25 g/cc would load at 12.88 lbs./ft. That is an increase of over 5 lbs. for every foot of borehole loaded, which in our example would be a difference of over 16,800 lbs. in the whole blast.

There are some products that are beyond the scope of this article, in which the product density is intentionally altered throughout a column of explosives, so that different product characteristics can be obtained at different depths in a borehole. In these cases, densities are carefully monitored and logged throughout the whole loading process so that accurate weights and product mixes can be recorded. In many systems in use today, the mixing process and the record of the amount of product used is all calculated automatically by a computer as each hole is loaded according to specific parameters.

Regardless of the product or the operation, density is an important factor when it comes to explosives, and not just because it can be used to determine the weight of explosives used in a blast. For reasons best described through chemistry, which we will not get into here, explosive products are most effective when they are blended to meet a specific product density. If product density is off, then the energy produced by the explosive will probably not be optimal. That means a lot of hard work and expensive raw materials will have been used to produce less than desirable results.

Given all of this we can safely say that it would not benefit a blasting contractor to alter the product density of a site mixed product, such as an emulsion, because it would negatively impact the efficiency of the explosive itself, which would be easy to see in the results of the blast. And we can safely say that since many products have fairly standard product densities, it would also be unlikely that those numbers could be changed by more than a few hundredths of a g/cc, and there really would not be much reason to do so. And we can safely say that because products with variable densities have to be so carefully monitored and mixed, it is unlikely that those product densities would be intentionally misreported to any great extent. Which leaves us with the possibility that a blasting contactor could lie about what kind of product they were using in a particular blast or the actual product density.

First, let's consider what the benefit would be of a blasting contractor reporting a different product than they really used to their customer. It is difficult to see where this would result in any kind of benefit. In a cost per unit scenario, the heavier product would mean more expense to the customer than they are used to being billed for, which would have to be explained by their vendor. If the heavier product were used and not billed to the customer, the blasting contractor would have to absorb those costs. In a cost per ton scenario, the contract was probably based on the use of certain products at known densities. Making changes to product weight and quantity would mean that the blasting contractor would again have to absorb any product cost overruns that the cost per ton contract does not take into account.

Nor would it benefit the contractor or the customer to use a different product in quarries where the rock reacts best to being blasted using certain types of products. Different explosives have different detonation characteristics, and different kinds of rock shatter and heave better when using certain types of explosives over others. For this reason, some quarry operators have very specific requirements regarding the types of explosives they want to see used in their mine.

Finally, however improbable it may be, could a blasting contractor or mine operator benefit from concealing the true product density they are using in their post-blast report? Perhaps, if they were slightly over their maximum weight or scaled distance limits and doing so would mean bringing their scaled distance values or maximum weight per delay to within regulatory limits. There are other reasons one might skew their product densities, but this would probably be the most tempting.

Even still, three things must be considered: 1) the vast majority of blasters are not out there misrepresenting what they are doing, 2) unless a contractor were using a completely different product than they were reporting we would only be looking at density differences of a few hundredths of a g/cc for the numbers to make any sense (difference in weight by change of hundredths g/cc shown in figure 6 below), and 3) if a blaster were using different products than they reported, and those products were of significantly different densities, it could quickly become evident in the increase in vibration since vibration generally increases with charge weight, as shown in figures 7 and 8 below.

	Change in product weight and predicted vibration when density increases by hundreths of a g/cc		
	Density	**Weight per column**	**Pred PPV Increase**
Product such as ANFO	0.82	363.18	0.1257
	0.83	367.61	0.1268
	0.84	372.04	0.1279
	0.85	376.47	0.1289
	0.86	380.90	0.1299
Emulsion type product	1.23	544.77	0.1663
	1.24	549.20	0.1673
	1.25	553.63	0.1682
	1.27	562.49	0.1700
	1.28	566.92	0.1710

Figure 6

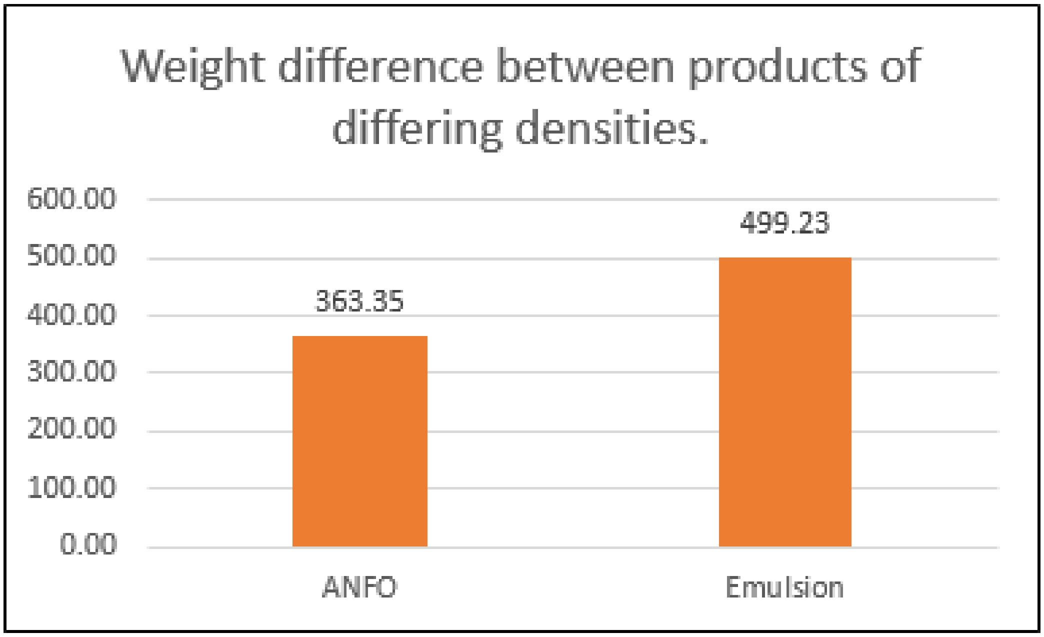

Figure 7

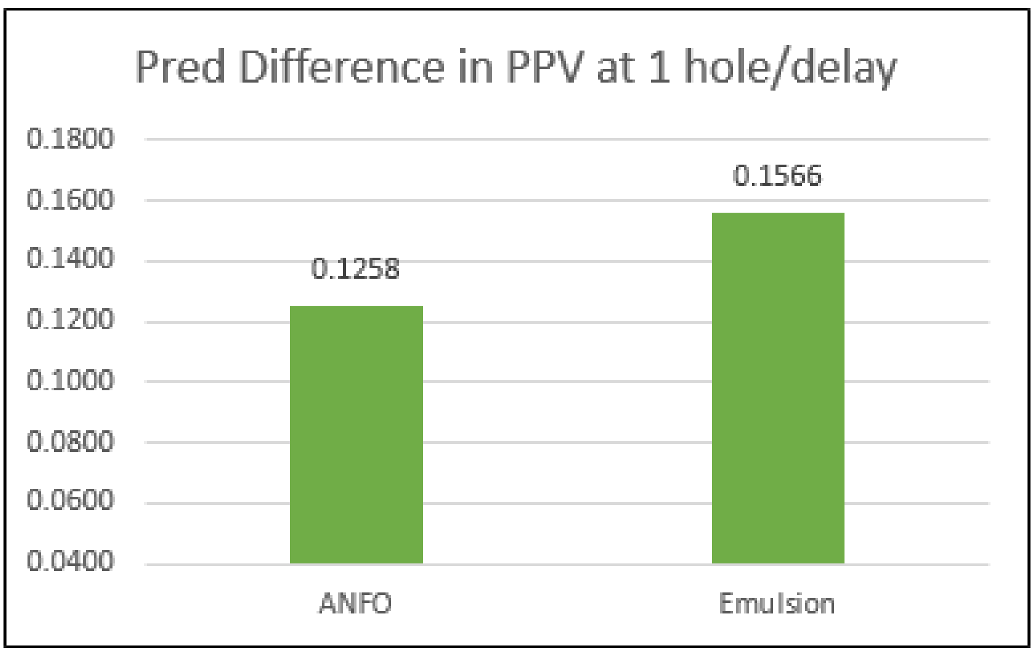

Figure 8

Of the four methods considered so far, this one has a higher degree of likelihood and purpose, yet it would be reasonably discoverable in the third instance where a significantly heavier product than reported was actually used.

Method 5: The last method by which a blasting contractor could use larger quantities of explosives than they reported would be if they increased the diameter of the boreholes without noting the change in diameter on their post-blast report. Of the five methods considered here this is the option that could produce physical results that could benefit the operator enough to make the risk of being found out and the effort expended worthwhile, and that probably only if the operator were willing to work with the contractor to accept higher costs, since doing so on a regular basis would quickly become too expensive for the contractor to absorb on their own.

First, let's consider why an operator or contractor might be tempted to use a larger hole diameter than they actually did. Blasting permits generally specify the maximum weight of explosives per delay that may be used and the minimum scaled distance requirements under which blasting must be conducted. Human nature dictates that there will always be those who push those limits to the edge of their allowable range. When that happens there is little margin for error between operating within the limits of a permit and going over the limit.

Making small changes to things like hole diameter and product density could be just enough to bring those numbers to within regulatory limits. I am aware of one operation that changed their reported hole diameter by 1/8th inch in order to report slightly lower weight per borehole than they actually used. It was only a difference of 26 lbs./delay, but at a distance of approximately 580 feet from the nearest unowned structure, it brought the scaled distance up by about 1.08. That little change could be enough to bring a mine operating at the edge of what their permit authorizes to appear to be in compliance on paper.

Another number that is important in blasting is known as powder factor. Powder factor is the ratio of explosives used to the amount of rock being blasted. Most often in the United States powder factor is calculated to yield results either in lbs. of explosives per cubic yard of rock, or tons of rock produced per lb. of explosives. Going forward here, we will think of powder factor in terms of lbs. per cubic yard.

Since powder factor is dependent on the volume of rock blasted and the distribution of a given weight of explosives used in that mass of rock, it can fluctuate based on how holes are loaded and the blast design parameters. So, if a borehole diameter is increased and nothing else changes, the lbs. of explosives used per cubic yard of rock increases. There are other factors that affect rock breakage, such as stiffness ratio. Powder factor alone is admittedly a poor indicator of expected blast performance. However, for our purposes here, let's assume that increased lbs. per cubic yard has been shown to yield better rock breakage and a better cast in our imaginary mining operation. Therein lies another possible temptation to alter hole diameter without reporting it in a location where a mine is restricted to a certain hole diameter.

Now that we know why someone might do this, let's consider whether or not it would be worthwhile from a production standpoint, followed by whether or not it would be readily discoverable by a regulatory official examining their blasting practices.

A borehole of a certain diameter has a certain volume that may be filled up with explosives. The volume of a borehole increases exponentially, not linearly, as the diameter increases. In other words, a 6-inch diameter borehole does not have twice the volume of a 3-inch diameter hole, but rather has about 4 times the volume of a 3-inch borehole. So, small changes in diameter can lead to significant increases in the amount of explosives loaded, as shown in figure 9 below.

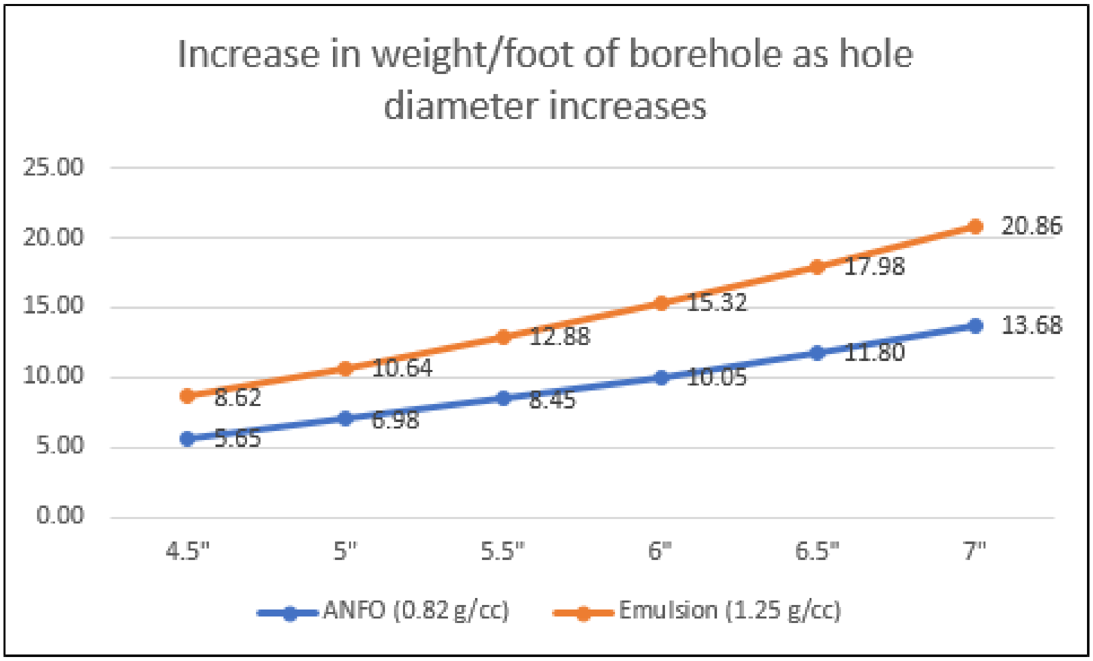

Figure 9

We have already shown how vibration increases with charge weight (see figures 2, 5, 6, and 8 for reference). So, any relatively significant increase in charge weight should be reflected in the vibration produced by the blast. And, since we can predict a range in which we would expect to see the vibration levels fall, an investigator could conceivably determine with a reasonable degree of certainty that something is askew if the increases in explosives used were great enough to exceed any margin for error that might exist in the prediction formulas.

Knowing the information shown in figure 9 we can easily determine that for a 5.5-inch diameter borehole of 53 feet in depth, loaded with a column of emulsified explosives 43 feet tall, the charge weight would be 553.84 lbs. If the blasting contractor increased their hole diameter by one half-inch, to make it 6-inches in diameter, the weight for that same column of explosives would increase to 658.76 lbs. That is an increase of almost 105 lbs., or over 7860 lbs. distributed across the entire blast of 75 holes. If ANFO was being used instead of emulsion the increase would be less.

If we calculate the predicted vibration that increased hole diameters would produce, assuming nothing else is altered, we get the results shown in figure 10 below. An increase in predicted vibration is an easily identifiable trend on the graph, however increases in vibration as hole diameter increases by the half-inch are close enough that it would be difficult to identify that much of a deviation as being much more than an anomaly within a margin of error. For example, the change in predicted vibration following the emulsion line between a 5-inch diameter hole and a 5.5-inch diameter hole is only an additional 0.0207 in/sec, hardly a difference that would raise concern unless peak particle velocities were already at or near regulatory limits. Even increasing hole diameter by a full two inches, from 5 inches to 7 inches results in a predicted increase of only 0.0871 in/sec.

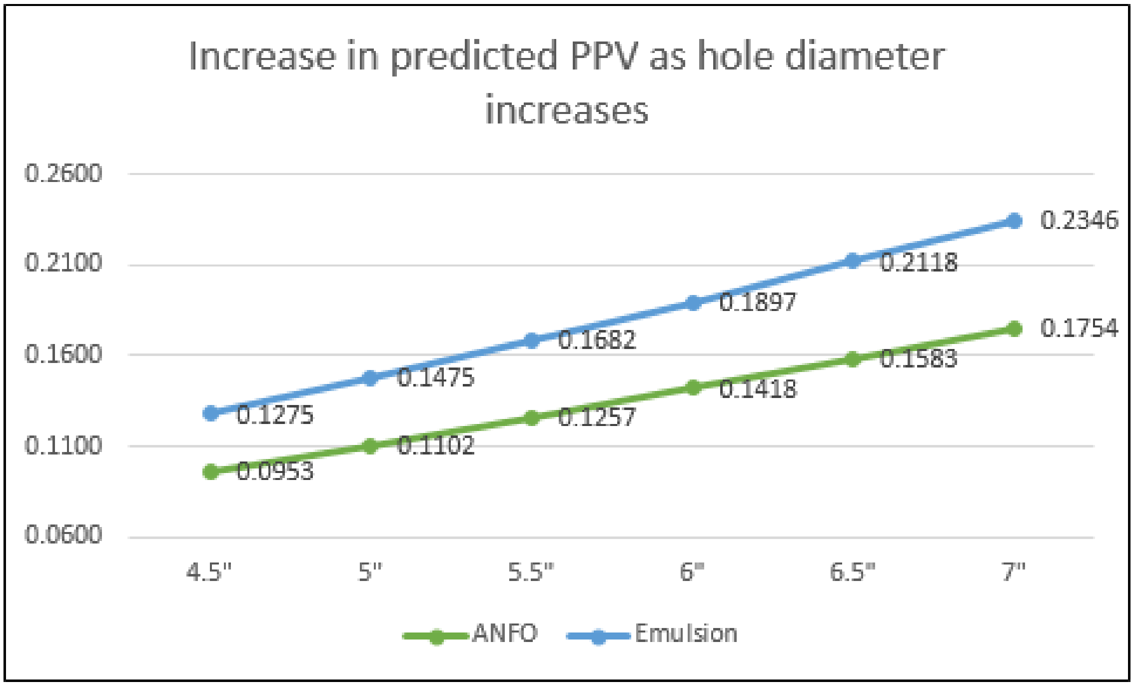

Figure 10

If vibration readings are already low enough that they are clearly well below regulatory criteria, whether the USBM Z-Curve or other criteria, such low increases would probably not raise alarm during a review of records. On the other hand, if vibration frequencies were low enough that the readings plotted closer to the Z-Curve line, then it might become more noticeable.

Unreported increases in hole diameter could be discoverable with a thorough review of records during an investigation, if increases were large enough, especially if the average regression of peak particle velocity was known for the site. However, it seems highly unlikely that small unreported changes would be caught with a basic records review.

Other reasons more explosives than reported might be detonated in a blast

Blasting is a time intensive process that requires a high level of experience, skill, and technical understanding to do it well and safely. Yet there are numerous variables that cannot be adequately analyzed on paper: hole diameters can vary naturally as drill bits wear out and rock layers change, water can infiltrate a bore hole making a portion of a powder column ineffective, and cracks and cavities can be present in the rock formation, which if not known about and attention is not being paid, can lead to larger pockets filled with explosives. Any of these variables could increase or decrease the expected amount of explosives that could be effectively detonated in a borehole, however, usually not to a level would cause enough additional energy to pass through the ground to surrounding structures to cause damages.

In addition to problems with boreholes leading to more explosives loaded than intended, geologic anomalies between boreholes could lead to sympathetic propagation, a condition where the detonation of one hole imparts enough energy to an adjacent hole to cause it to fire nearly simultaneously. While this is not the same as loading more explosives than reported, it would result in a greater quantity of explosive material being detonated within the same timeframe than otherwise expected, and since it is not always known that it happened, it may go unreported. This is an unusual circumstance, but it has happened.

Difficulties in falsely reporting explosives inventories

Explosives companies are under heavy regulatory pressure to maintain consistent and accurate explosives inventory records. These companies are subject to regular inspections and audits of their records by both state and federal agencies, which include the Pennsylvania Department of Environmental Protection (PADEP), the federal Department of Transportation (USDOT), and the federal Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF). Under the rules of these agencies explosives companies are required to maintain accurate, consistent, and up-to-date records of all dispositions and acquisitions of explosive materials and constituent materials. Any failure to do so can result in serious regulatory action, including the loss of licenses and permits to use explosives, loss of storage licenses, fines, and in some cases even criminal charges. The records of explosives inventories must be produced on demand during an audit or investigation. Audits of records related to explosives occur regularly.

Now more than ever, security awareness is taken seriously at all levels within the explosives industry. That said, there is still work to be done to improve how inventories of bulk materials are tracked and recorded. While magazine inventories of high explosives and detonators are easy to confirm and track with a high degree of accuracy, bulk product inventories are still notoriously difficult to track and confirm. A couple of thousand pounds of bulk materials over the course of a year or even a quarter-year could easily go misreported and could remain forever unknown. However, with regard to the topic of this paper, such discrepancies leading to enough of an increase in the pounds of explosives used in a blast to increase the amount of vibration energy experienced by surrounding structures, could be discovered through an investigation that takes into account the aforementioned means of discovering anomalies in reported pounds of explosives and vibration levels.

Conclusion

The commercial explosives industry is both heavily regulated and self-policing. Industry regulators and consultants routinely investigate complaints of all sorts and regulatory officials conduct regular inspections to try to ensure that blasting is being done in way that ensures the safety of surrounding people and their properties, the environment, and the personnel who work at the various mines and construction sites where blasting is employed. However, as with any industry from truck driving to medicine, professional conduct and willingness to submit to regulatory criteria are vital.

For the most part, blasting contractors and mine operators are not running amok, doing as they please and hiding the amount of explosives they are using to do their job. That said, there are always those who push the bounds of what is safe and permissible. For that reason, we have regulations and people whose job it is to enforce those regulations, as well as industry consultants whose business it is to help companies employ best practices and to adhere to regulations. When we have to evaluate a complaint or an allegation, we have to conduct research, look at the operation itself, and come to conclusions about the allegation that has been made.

In this paper, an examination was made of means by which a blasting contractor could use more explosives than they are reporting and conceal that from anyone examining the blast after-the-fact. We also looked at the benefits or lack thereof of using and concealing greater quantities of explosives than reported, as well as some of the negative consequences of doing so.

In conclusion, an operator could use more explosives than their post-blast report indicates, or even more than their permit allows them to use. By changing things such as hole depth and hole diameter additional quantities of explosives could be loaded into a blast. We have looked at the apparent increases of explosives as certain variables were manipulated, and we have seen varying degrees of ease with which additional quantities of explosives might be used and concealed. However, we have also seen in our examples that even if someone clandestinely increased the amount of additional explosives used, vibration increases were not as significant as one might expect.

Given the risk versus reward of using and hiding more explosives than reported, it appears improbable than someone would do this to any great extent, and if they did, unless the vibration levels were already close to damage criteria or regulatory limits, the net effect of using the additional explosives would be unlikely to cause blasting related damage that would not have otherwise occurred.