Evaluation of Report entitled "Multiple Seed Waveform (MSW) Site Vibration Characterization – Signature Holes and Production Blasts, and Air Pressure Estimate" (Yang and Pratt, 2011)

P.D. Katsabanis, Ph.D., P.Eng.,
Rock Dynamics International Ltd.

Introduction

Blast vibration prediction is traditionally done on the basis of a vibration attenuation law, which relates the peak particle velocity of the ground to scaled distance. The equation commonly used is the following:

$$PPV = K\left(\frac{R}{W^{1/2}}\right)^{-m}$$

where R is the distance and W is the mass of explosive detonated inside a delay window, commonly called mass per delay and K and m are site constants (K, m >0).

The equation is a simplification and does not constitute a sound physical law (Blair, 2004). It works fairly well in single shot environments, where site constants can be calculated with reasonable statistical accuracy, but in the case of multi-hole production shots, the relationship between particle velocity and scaled distance suffers from the scatter of experimental observations. The scatter is related to a variety of factors, such as the geology and confinement of the shot, but an important fundamental reason is the fact that particle velocity is not a single observation in time but a time history of particle velocities. Thus the superposition of waves produced by the many holes of the blast creates the vibration wave of interest and, consequently, timing between the detonating holes of the blast becomes an important parameter, ignored in the above equation. Furthermore timing affects the frequency of the vibration wave, which typically affects structural response due to the vibration. Thus modern prediction of blast vibration uses better tools than the above equation.

Anderson and Brincherhoff (2008) and Wheeler (1989) have suggested the use of a signature vibration waveform to model production vibrations by the superposition of the signature wave and time shifting according to the delay times of the blast. The technique is typically used for far field vibration monitoring, assuming that the distance between holes is insignificant to the distance of the monitoring station. The technique also implies that the waveforms produced by each of the holes of the blast are identical and described by the signature waveform, which is captured in a different experiment. It is also implied that the time of detonation of each hole is accurately known, something that used to be a problem in the past, when pyrotechnic detonators were used, however electronic detonators are in common use today. Thus firing times of charges are well known and there is a great deal of choice as far as actual delays are concerned.

Yang and Scovira (2010) have recognized that this approach is not adequate for modeling of vibration relatively close to the blast, where distances between boreholes are important relevant to the point of interest, where a monitor would be placed. They developed a technique of vibration synthesis on the basis of multiple “seed” waves, which are waveforms recorded at different distances from a signature hole. Thus the change of waveform, both in amplitude and frequency due to the change of distance, can be accounted for, and vibration modeling can be performed. This is the technique, which has been used in the case of the proposed Ajax mine.

In the following, the report by Yang and Pratt (2011) will be critically reviewed and then the findings will be discussed with regard to whether the ability to comply by published vibration rules in the surrounding communities has been demonstrated.

Critical review

Of major importance, to this reader, are the vibrations levels in the surrounding communities as well as the vibration level at the neighbouring pipeline. Compliance, predicting very small levels of vibration and air blast, has been demonstrated for the two small-scale blasts that were conducted in overburden and ore respectively. This only means that a blast accurately described by the small-scale blasts will produce similar and compliant events. Such a blast would have the same burden, spacing and loading as the small scale-blasts, the same number of holes per row and the same number of rows, the delays would be identical to the ones used and the location and geology would be the same as the small-scale blasts. The agreement between prediction and result is very good but this only serves as a verification of the model. The model’s predictions for large-scale blasts, in different locations of the proposed mine would be of interest as far as compliance as well as measures to assure compliance are concerned.

The report provides scant information on the experimental procedures that were followed. The characteristics of the signature holes would be of interest to the reader. Such information is at minimum the diameter, burden, loading, priming and location. The monitor locations are given on a map, but the information is not adequate to obtain distances between blasts and monitors. Distances are given later, for one signature hole and six monitoring stations, where the results are presented. However, there are 7 signature holes, thus a significant amount of information is missing. The information would have been useful in understanding the differences in the amplitudes recorded by the monitors as well as the change in frequency with distance.

Type, make and specifications of vibration monitors are not given. The information matters; one does not doubt the accuracy of the information provided nor the analysis performed but it is important that the independent reader has enough information to make an assessment of what was done.

Details of the small production blasts are not given. It is important to know loading, burden and spacing and not just timing. Understandably timing is probably the most important factor as loading and burden were most likely equal to those of the signature holes.

It appears that air blast measurements were taken from monitor #8. Why noise was not recorded elsewhere is not clear and the scatter of measurements in Figures 9 and 10 (Yang and Pratt, 2011) is of interest. The report suggests that the scatter could be due to confinement. Therefore, information on confinement (collar height, stemming type, burden and burden condition) ought to have been provided in the report. Of interest is also the presentation of the air blast information in terms of decibel vs. scaled distance. Apart from the use of the square root of the weight in the scaled distance term, while the commonly accepted method is the cube root scaling, the pressure is in a logarithmic scale (dB); therefore the scaled distance ought to have been in a logarithmic scale as well. This would not have changed matters as far as the presentation of data is concerned; it would have made things consistent between Figures 9, 10 and 11 (Yang and Pratt, 2011). It would have been of interest to disclose the minimum distance from future blasts to residences in order for the reader to estimate the pressure levels expected from a blast similar in design to the small scale production blasts, or, given an overpressure limit, the maximum charge mass per delay that ought to be used. Details on the Orica overpressure model are not presented; the reader thus assumes that it is a simple pressure attenuation law, commonly used by the industry.

The results of the model have been compared against measurements for small-scale blasts. The agreement between prediction and measurement appears to be good for scaled distances of 24-28 m/kg$^{0.5}$. This corresponds, according to Tables 6 and 7 (Yang and Pratt, 2011), to distances up to 600 m. It appears that the small-scale production blasts would result in a peak particle velocity lower than 12 mm/s at distances larger than 400 m. Whether this is safe, depends on the frequency of the vibration. For example according to the USBM criteria, 12 mm/s is safe for plaster, as long as the frequency is above 3 Hz (Oriard, 2002). The German regulations (DIN 4150-3, 1999) specify vibration limits below 12 mm/s depending on type of structure and frequency. At low frequency (less than 10 Hz) of vibration, the suggested limit for “particularly sensitive buildings” is 3 mm/s, for “dwellings” it is 5 mm/s and for “industrial buildings” it is 20 mm/s. In any case, the frequency of the vibration is also important for structural response and perception of vibration, so a discussion on predicted particle velocities and frequencies at distances of interest is needed.

The report has shown that the vibration and air blast levels will be of insignificant magnitude at distances 2800 to 9000 m for blasts similar to the small scale blasts at the current location. Given the demonstrated attenuation of vibration and air blast levels (Figures 25, 26 and 11 in Yang and Pratt, 2011) this is reasonable. Some changes may be expected from a full-scale blast as timing and pattern play a role on the superposition of vibration waves. A significant number of holes detonating within a short period of time may create some increase of the vibration and air blast levels. Each pattern and delay time will result in different levels of vibration; thus representative patterns may be simulated to demonstrate compliance or how to achieve compliance using blasting techniques such as decking or by properly selecting delay times for the blast pattern.

Discussion

Thus, it appears that in the Orica report (Yang and Pratt, 2011) the Multiple Seed Waveform model has been verified for blasts similar to the small-scale production blasts that resemble the geology and confinement of the ones performed for the verification of the model. One would however be interested in how the model would perform where the pattern is more complex in terms of a larger number of rows and holes and in the case in which different timing is used. Given the fact that the model is only dependent on the attenuation characteristics of waveforms produced by single holes and the frequency change of the waveform with distance, one would expect reliable results. This is not however discussed in Orica's report. Yang and Scovira (2010) have produced evidence of successful modeling of Blast Vibrations in the case of more complicated patterns where the charge per hole varied from 31 kg to 707 kg and hole depth varying from 6 m to 15 m according to topology. The blast patterns consisted of several rows and each contained from 38-206 holes. According to the authors, the ability of the model to predict vibration results from blast with a variety of designs is indicative of its predictive capabilities. In the same publication, Yang and Scovira (2010) have demonstrated the use of the model to enable the user to select proper delay timing for vibration control by predicting the result of changing delays on the peak particle velocity of the blast that was modeled. They showed that a delay of 25 ms would be preferable to a delay of 17 ms using the model and have produced a favorable comparison between model prediction and measurements in the case of the two delays examined. Delay selection is important and the model does offer a way to optimize the selection of delays. Results of the effect of delay on frequency of the resultant vibration wave have also been demonstrated in the same publication. The comparison between predicted principle frequencies and measured ones was good. Thus the ability to shift dominant frequencies using proper delays was also demonstrated together with the ability of the model to predict the shift. In a similar publication Yang and Kay (2011) have demonstrated good agreement between measurement and prediction for the case of underground tunneling blasts where the cut holes were used as seed waveforms for the model. The paper demonstrates predictive capabilities obtained with seed wave forms in the same geology and for a rather complex blast design having a variety of delay times starting from 150 ms at the cut, to 40 ms for production holes and 5 ms at the perimeter holes.

Conclusion

Thus, on the basis of existing publications, it appears that the model is capable of predicting blast vibrations on the basis of seed waveforms that have to be recorded prior to the blast and that the model is accurate even in complex design situations. It is reasonable to expect the model to be used in calculating the results of realistic, complex, full-scale blast designs, something that has not been demonstrated in the report by Yang and Pratt (2011). One does not know the expected vibration wave from a typical blast design as the mine approaches its perimeter, if compliance issues are expected and how they will be resolved. It is understood that the blast design will change as more information about geology and rock properties are collected and experience is accumulated by the everyday operation. However initial estimates on the vibration levels can be produced by the model.

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