Case Study

Dispute Resolution in the Mining Industry: Lessons Learned from the Effects of Blasting on Nearby Structures

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Abstract: Blasting is a common practice in surface mining operations to remove waste rock and to excavate mineral deposits. However, blasting creates adverse effects such as blast-induced ground vibrations, air overpressure, dust, fumes, and flyrock. Residential communities living close to a mine site and other structures in the vicinity of a mining operation are subject to blast-induced damages. Humans can perceive low-level vibrations from blasting events that cause house to shake. They become concerned about cosmetic or structural damages due to blast-induced vibrations and air overpressures. Some cosmetic and structural damage claims from the community are legitimate. However, many are found to be false during the investigation of citizen complaints. In these instances, monetary compensation is still expected, on the basis that damages were solely due to blasting activities in nearby mines. This study presents cases and investigations to resolve owner-filed complaints for regulatory action and monetary compensation. It emphasizes recordkeeping and monitoring of blast operations, from which two positive outcomes result: (1) assisting regulatory authorities in assessing compliance with blasting regulations and prevention of damage to structures; and (2) helping the mining industry identify critical blasting information needed to protect nearby structures minimize liability claims. **DOI: 10.1061/(ASCE)LA.1943-4170.0000487.** © *2021 American Society of Civil Engineers.*

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Introduction

Blasting is a common practice in mining operations to remove waste rock and to excavate mineral deposits. It is still considered the most economically viable large-scale rock breakage method, used in mining as well as construction (Erten et al. 2009; Stark 2010). However, ineffective and inaccurate blast designs create excessive adverse effects such as ground vibrations, air overpressure (airblast), dust, fumes, and flyrock. Residential communities close to a mine site and structures (gas lines, power poles, communications towers, etc.) in the vicinity of a mining operation are subject to blast-induced damages. Studies on how to predict and analyze blast-induced ground vibrations and air overpressures in the vicinity of limestone quarries can be found in studies by Adhikari et al. (2004), Chen and Huang (2001), Kahriman (2004), Kuzu and Ergin (2005), and Ozer et al. (2008). The literature has also tackled prediction of explosive charges for efficient mining operations (Singh et al. 2006) and prediction of ground vibrations due to construction blasts in different types of rocks (Aloui et al. 2016; Tripathy and Gupta 2002). The elements to be evaluated to resolve damage complaints include reviewing blast logs, inspecting mines and nearby houses, reviewing monitoring data (ground vibrations and airblast), and predicting vibration levels at the claim location (Eltschlager 2001).

Human perception of vibration during a blasting event is hard to measure and is dependent on the intensity of structure response. Often the structure occupant claims cosmetic or structural damages due to blast-induced vibrations and air overpressures. Gad et al. (2005) found the the human body to be an excellent detector of vibration but a poor measuring device. Occasionally there are legitimate cosmetic damage claims due to blasting in nearby mines, but there are also false claims in dispute resolution reports where homeowners have claimed monetary compensation, arguing that the damages were solely due to blasting activities.

In January 2020, the Charleston, West Virginia field office of the Office of Surface Mining Reclamation and Enforcement (OSMRE) received a blasting damage complaint from the owner of a residence in Mingo County, West Virginia. The West Virginia Department of Environmental Protection (DEP) was asked to provide information related to the damage claim and its analysis. Similarly, in January 2020 the Virginia Division of Mined Land Reclamation (DMLR) requested technical assistance concerning a long-running blasting complaint that alleged damage to a residence located in Wise County, Virginia. Regarding both claims, investigation reports show that no damages to nearby residences were found because of blasting.

The objective of this study is to present findings and lessons learned from the two recent claim reports that can help regulatory authorities assess compliance with blasting regulations and assist the mining industry in protecting nearby structures and minimizing liability claims. The study presents strategies and technologies to assess damage and mitigate claims during dispute resolution. A case study methodology accomplishes this objective.

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Background

Adverse Effects of Blasting

The adverse effects of blasting include ground vibration, air overpressure/noise, flyrock, dust, and fumes (Singh et al. 2006). While flyrock damage is obvious, ground vibrations and airblast also cause damage to residential structures. Bhandari (1997) concluded that many factors affect the propagation of ground vibration, making it almost impossible to incorporate all ground vibration parameters in a single empirical equation. Ground vibrations and airblast beyond the blast site are strongly dependent on charge weight per delay, confinement, and distance (Crum et al. 1992; Stiehr 2011). They are also affected by blast design, as errors in drilling, loading, and wiring can be problematic. Studies have correlated vibration parameters (displacement, velocity, acceleration, and frequency) with human disturbance and damage to structures (Crandell 1949; Dowding 1996; Kisi et al. 2020; Medearis 1977; Siskind et al. 1980).

Square-root scaled distance versus particle velocity and cube-root scaled distance versus airblast are generally used for blast vibration prediction. The most widely accepted single measurement of ground vibration potentially damaging to structures is peak particle velocity (PPV), defined as the speed at which an individual earth particle moves or vibrates as waves pass a particular location (Abdel-Rasoul 2000; Singh et al. 2006). Duvall and Fogelson (1962), Nicholls (1971), and Wiss (1968) concluded that structural damage best relates to ground vibration PPV. Siskind (1980) identified ground vibration frequency as an important parameter in blast damage. Siskind et al. (1980) correlated airblast-induced damage with air overpressure measured in decibels.

The characteristics of blasting vibrations depend critically on quantity of explosives detonated at any given time, delay intervals in the blast design, charge confinement, and geological conditions. Optimized delay between holes and rows can give better fragmentation and lower vibration levels (Singh et al. 1996). When an explosive charge in a blasthole is detonated, it releases a large quantity of chemical energy that simultaneously changes its form to a hot gas at high pressure (Hopler 1998; Stiehr 2011). Following detonation, two energy forms are generated: shock wave and gas pressure (Djordjevic 1995). The detonation of explosive charges causes dynamic stresses to be generated around a blasthole, which in turn produces elastic deformation propagating away from the blast area in the form of seismic waves (Jaeger and Cook 1979). Any constriction in rock mass movement (confinement) increases particle velocity and decreases blasting efficiency.

Blasting Vibration Effects on Nearby Structures

Srbulov (2010) explained that the number and type of vibrations that reach a site depend on (1) amount of energy released at the source, (2) energy travel path from the source to the site, (3) distance from the source to the site, and (4) site characteristics. Both natural phenomena, such as earthquakes, volcanoes, and landslides, and man-made phenomena, such as blasting, can cause vibrations. Though vibrations travel differently in varying geological units such as hard and soft rock, the distance from the blasting source to the monitoring site is important because the greater the distance, the greater the attenuation of the vibration energy (Connolly 2018). Waves generated from blasts affect structural responses to them. Connolly (2018) discussed body waves and surface waves that travel at different velocities, resulting in body waves reaching the structure before surface waves. Study of blasting vibrations, PPV, and frequency has become essential in providing guidelines for safe blasting in terms of minimizing damage to residential structures (Dowding 1996; Siskind et al. 1980; Yugo and Shin 2015).

Structural Vibrations/Response

Ground vibrations enter a structure at the foundation or ground level and airblast through the roof or building sides. As a result, the part of the house above ground shakes or otherwise responds. A typical house will respond to airblast one to three times the ground vibration level and to a natural frequency between 4 and 12 Hz. The higher amplification occurs when the frequency of the ground or air vibrations matches the natural frequency of the house, causing the house to resonate (Eltschlager 2020a, b). In other words when the frequency of the incoming vibrations matches the natural frequency of the house, the house will ring. The greater the difference in frequencies between the vibration of the ground and that of the house, the less the house responds and the less damage potential results.

The United States Bureau of Mines (USBM) report of Investigation (RI) 8507, *Structure Response and Damage Produced by Ground Vibration from Surface Mining* (Siskind et al. 1980) and report of RI 8485, *Structure Response and Damage Produced by Airblast from Surface Mining* (Siskind 1980) established methods for monitoring responses of houses to ground vibration and airblast. USBM RI 8507 analyzed homes of various designs for their response to vibrations and summarized data from previous studies. The typical design of the houses was one to two stories, frame construction, and foundations. Most were considered typical of the single-family houses commonly found near surface mines.

According to Siskind et al. (1980), the vibration limits from blasting in USBM RI 8507 remain the most restrictive in existence. They are based on measured structural responses and observations of cracking correlated to specific vibration events. USBM RI 8507 limits provide a guaranteed safe level for blasting and limits suitable for regulations. They account for the widest possible range of levels and worst-case conditions for residential structures. These limits consider the frequency of vibrations as well as peak particle velocity.

The USBM recommends safe vibration amplitude limits of 0.0127 m/s (0.5 in./s) for ground vibrations when frequencies are low (<40 Hz; Siskind et al. 1980) and 133 dB for airblast. The recommended limits assume that most homes respond similarly. If the house is unusual in construction, materials, dimensions, or age, the response characteristics may need to be observed to determine safe vibration levels or gauge the damage potential.

Blasting Vibration Regulatory Limits

The USBM began recommending vibration criteria in 1942 in attempts to respond to concerns over blasting causing structural damage to nearby housing developments (Reed 2005). The vibration criteria presented in in USBM RI 8507 (Siskind et al. 1980) are still used in the mining industry today.

RI 8485 (Siskind 1980) generally recommends a maximum safe overpressure of 0.089 kPa (0.013 psi) for airblast recorded at residential structures (Siskind et al. 1980). This criterion is based on superficial damage to residential structures, with a recommended safe maximum airblast level of 133 dB, measured by a 2-Hz high pass system, providing 95%–99% nondamage probability and 95%–90% annoyance acceptability. Airblast is an undesirable and unavoidable output of blasting that propagates as a compression wave in air. Airblast damage and annoyance may be influenced by factors such as blast design, weather, field characteristics, and human response.

Surface structures tend to amplify ground vibration when the dominant frequency of the vibration matches a structure's natural frequency. Medearis (1978) showed that natural frequency is related to structure height and varies between 4 and 18 Hz. When the natural frequency of a structure is close to the frequency of blast-induced ground vibrations, a significant amount of ground vibration energy transmits to it, which results in oscillations increasing in amplitude. Therefore, the frequency of measured ground vibrations should be considered in the evaluation of structural damage (Erten et al. 2009).

If a residence generating a complaint is one of the building types covered by the USBM, it should respond in a known way. Thus, the vibration levels recommended by USBM RI 8507 and RI 8485 (Siskind et al. 1980; Siskind 1980) and adopted by OSMRE, states, and other regulatory authorities, should prevent damage to residential structures.

Case Study Methodology

The research team used a three-step approach to study the effects of blasting on nearby structures and present findings.

1. Reviewing newspaper articles, conference and journal papers, and technical reports;
2. Selecting two detailed case reports for analysis; and
3. Drawing conclusions from analysis of the case studies.

Case Study 1

In January 2020, the West Virginia DEP received an allegation of blast vibration damage to a residence in Mingo County, West Virginia, caused by blasting associated with a coal mine. The complainant (owner) believed that the damages occurred sometime after January 1, 2019.

The DEP subsequently inspected the mine, reviewed blasting records viewed the alleged damages, and issued reports dated May 20, 2020, and August 20, 2020. The structure was a double-wide mobile home about nine years old which had been added to some years back. The home had concrete footers and sat on cinder blocks. The complainant also had a garage separate from the house. It too rested on footers and had cinder block foundation.

Damage Claim

The alleged damages to the home were

- Cracks in the dry wall on the ceiling and on the walls in several rooms;
- Cracks in the foundation blocks of the garage and the home;
- Separation of trim next to the ceiling;
- Cracks in the garage floor;
- Cracks in the driveway;
- Leaking between the panes of a French door; and
- Concrete crack in the garage floor at the garage opening and a stucco crack in the block foundation underpinning.

A DEP review of the preblast survey showed that some of the damage was preexisting. It included a renovation survey due to recent upgrades to the home.

The closest blasting to the complainant's residence since January 2019, on January 4, 2020, was 1,076.25 m (3,531 ft) away. The shot used 719.39 kg (1,586 lbs) of explosives per 8 ms of delay. According to the predictive equation, the home would have had a peak particle velocity of 0.003 m/s (0.127 in./s). The largest blast at the mine since January 2019 was on March 1, 2020, which used 1,142.6 kg (2,519 lbs) of explosives per 8 ms of delay and was 1,373.4 m (4,506 ft) from the home. The predictive equation indicated that the home would have had a peak particle velocity of 0.003 m/s (0.119 in./s). After reviewing information from the complainant (dates, times, and alleged damage) and from the company (blast logs and seismic records), the DEP found that the alleged damages did not meet the criteria for blasting damage. All distances were checked using GPS coordinates and Google maps.

The OSMRE investigation report reviewed the West Virginia DEP action and concluded that it was "reasonable and appropriate" on the basis of "the coal company permit information, the blasting logs, blasting seismograph records and West Virginia DEP complaint investigation reports dated May 20, 2020 and August 20, 2020."

Analysis of Damage

The most likely place that damage will occur from blasting is the above-ground portion of a structure unless the ground vibrations are extremely strong. Above ground, the house may vibrate more than the incoming ground vibrations if resonance is achieved and will respond to incoming airblast. Below ground, the structure will vibrate with the ground and will not respond to airblast.

According to USBM RI 8507, on ground vibration damage (Siskind et al. 1980), the first signs of blasting damage in typical homes, are evident in the interior walls. Hairline fractures begin to form at the union of typical gypsum wallboard (drywall) sheets at amplitudes of 0.019 m/s (0.75 in./s) if the frequency of the ground vibration is between 4 and 12 Hz. Cracks form on older, plaster-on-lath walls when ground vibration amplitude reaches 0.0127 m/s (0.5 in./s) with frequencies between 4 and 12 Hz. These cracks typically appear in the areas of angles around doorways and windows and where walls join.

Ground vibration levels necessary to cause structural damage, such as cracking of masonry foundation walls, must be considerably higher. Crawford and Ward (1965) reported that cement blocks failed along mortar joints at particle velocities of about 0.076 m/s (3 in./s) at high frequencies. Masonry damage appears as stair cracks from the corners. The highest estimated vibration level at the West Virginia plaintiff's residence was 0.003 m/s (0.14 in./s) with frequencies of about 10 Hz. This was well below the regulatory limits and in line with those estimated by DEP. Therefore, the investigators concurred with the state's findings.

According USBM RI 8485 (Siskind 1980), window breakage is the first sign of airblast damage and may occur at levels of 140 dB or higher. Airblast also causes midwall movements. Homes are very resistant to damage from midwall movements, but airblast does cause objects on the wall to rattle and move. The highest estimated airblast at the complainant's residence was estimated to be 121 dB and so carried no damage potential. Window breakage, normally the first sign of damage, was not alleged.

While ground vibration and airblast limits are set to protect structures from vibration-induced damage, low-level vibrations are allowable and are perceptible inside a building. Wall hangings and shelf knickknacks will vibrate and cause noise, which may be very annoying to occupants. Many household activities, such as walking, closing doors, and moving furniture, and environmental activities, such as thunder, traffic, or earthquakes, can cause vibrations similar to those caused by blasting [some as high as 0.0127 m/s (0.5 in./s)].

A preblasting survey of the complainant's structure was conducted on July 29, 2019. The estimated levels of 0.003 m/s (0.14 in./s) and 121 dB were, respectively, less than 28% and 25%, of minimum levels [0.013 m/s (0.5 in./s) and 133 dB] necessary to entertain a damage claim unless a structure is nontypical. The complainant's structure was determined to be typical based on DEP review, so further evaluation was unnecessary.

Findings

The West Virginia DEP issued the following findings:

- Ground vibrations at the complainant's residence were estimated to be below 0.003 m/s (0.12 in./s), but no estimate of airblast was made. On this basis, it was found that the coal company did not cause the additional cracks alleged by the complainant.
- Blast records were complete and critical information on the charge weight per delay and distances to the nearest structure, as reported in the blast reports, was accurate based on a OSMRE Blast Log Evaluation Program (BLEP) review (US Department of Interior 2019).
- The coal company provided blast-monitoring data from structures near the complainant's residence to help evaluate the complaint. None of the blasting seismograph records exceeded WV DEP vibration limits of 0.025 m/s (1.0 in./s) or 133 dB.
- Because of a lack of range in the data set, statistical analysis of the vibration data using the OSMRE Blast Induced Vibration Data Evaluation Program (BIVDEP) yielded poor results (US Department of Interior 2019). However, this was less important than the vibration-monitoring data available near the complainant's residence.
- Alluvial valley soils along Elk Creek and near-surface underground mines were keeping ground vibration frequencies low (about 10 Hz).
- The complainant's residence was a typical dwelling as defined by USBM RI 8507 and RI 8485 (Siskind et al. 1980; Siskind 1980). As such, it would respond to blasting-induced vibrations in a predictable manner. When vibrations are within the 4–12-Hz frequency range, this type of structure may resonate.
- When a building resonates from vibrations, the most likely place for damage to appear is in drywall or plaster high in the walls. The maximum ground vibrations estimated at the complainant's residence were 0.003 m/s (0.14 in./s) at about 10 Hz. At frequencies below 20 Hz, vibration levels need to exceed 0.019 m/s (0.75 in./s) to damage drywall or other building materials. At frequencies above 20 Hz, a structure will not resonate; ground vibrations of nearly 0.051 m/s (2.0 in./s) are needed to cause threshold/cosmetic cracking in drywall and plaster. Ground vibrations of more than 0.076 m/s (3 in./s) are needed to cause cracking in concrete or masonry,
- The maximum estimated airblast level at the complainant's residence was 121 dB. Cosmetic cracking would not begin until airblast levels reached about 133 dB for plaster-on-lathe structures. Window breakage might occur at levels above 140 dB.
- A typical structure would shake and pictures would rattle at any ground vibration and/or airblast level. The vibrations levels arriving at the plaintiff residence were very perceptible because of the low-frequency energy.

Investigator's Report

Within the boundaries of reasonable engineering and blasting certainty, and subject to change if additional information were to become available, the lead investigator (explosives/blasting engineer) reported that blasting at the coal company and conducted by the company's personnel did not generate ground vibration or airblast levels at the complainant's residence in excess of West Virginia DEP limits or recommended limits established by USBM. Therefore, the investigator concurred with the state's findings of no damage.

Case Study 2

On January 29, 2020, the Virginia Division of Mined Land Reclamation (DMLR) requested technical assistance from OSMRE concerning a long-running blasting complaint alleging damage to a residence. The residence was in Wise County, Virginia, and the blasting was associated with coal company operations. Specifically, DMLR asked OSMRE to evaluate the alleged damages.

Blasting near the residence, begun in February 2019, was carried out by a blasting contractor. The OSMRE investigation addressed the potential for damage to the residence because of blasting up to March 13, 2020. Its assessment was based on the company's permit information, blasting logs, blasting seismograph records, a preblast survey, and an inspection of the residence and the mine.

Damage Claim

The exterior of the residence was inspected with the complainant present on February 5, 2020. The complainant indicated that blasting was destroying his home and negatively impacting the coal pillars in the underground mine works beneath his residence. The complainant indicated that his front door had settled and had to be lifted in order to be opened; and also indicated that he had removed most interior doors because of settlement resulting from blast vibrations, The complainant pointed out other interior damage, including vertical drywall cracks and rolling/warping floors. However, this damage could not be observed because the complainant denied access to the interior. The vinyl soffit located above the front door in the front of the house had fallen down. The complainant attributed soft spots in his yard to subsidence from underground mine works resulting from blasting vibrations.

The residence was located on an alluvial terrace associated with nearby Pigeon Creek. The house was originally constructed as part of the Exeter Coal Camp. The complainant stated that the residence had been built between 1910 and the 1920 and had been remodeled in 1975. The plaster-on-lathe walls had been replaced with sheetrock/drywall, an existing porch had been enclosed, and an extension to the first floor with a second story had been added to the western portion. Cinder block walls constructed between the brick foundation piers supported the house and were covered with mortar.

The complainant lodged numerous complaints about blasting throughout 2019. Following is a summary of the DMLR Complaint reports.

Report No. 1, February 7, 2019

The blast on February 7, 2019, shook the house and one resident suffering from PTSD was disturbed. The blast records and vibration levels (ground and air) were reviewed and found to have followed state rules at two neighboring residences [0.0016 m/s (0.065 in./s), 113 dB] in the town of Exeter. The investigation was closed on February 12, 2019.

Report No. 2, March 6, 2019

The blast on March 6, 2019, caused the house to rattle and sustain damage, and caused the yard to settle. The blast records and vibration levels (ground and air) were reviewed and found to have followed state rules at both the water tank and at the complainant's residence [0.0017 m/s (0.07 in./s), 128 dB] in Exeter. The investigation was closed on March 19, 2019.

Report No. 3, April 17, 2019

Blasting was causing the house to shake, and dust control was an issue. Three blasts in April were reviewed. Two did not trigger the seismographs at the neighboring residence [trigger levels 0.0013 m/s (0.05 in./s), 120 dB]. The third blast caused a vibration of 0.002 m/s (0.08 in./s) and 105 dB at the complainant's residence. The blast records and vibration levels (ground and air) were reviewed and found to have followed the state rules. The investigation was closed on April 23, 2019.

Report No. 4, May 22, 2019

Blasting had shaken the house and had caused a crawl space vent to bulge and the yard to buckle. Additional concerns were blast-induced subsidence. A blasting seismograph was deployed at the residence on May 29, 2019, with trigger levels of 0.001 m/s (0.04 in./s) and 142 dB. A preliminary report dated May 30, 2019, found that the May blast records had been in compliance with state rules and that maximum vibration levels at the complainant's residence were 0.0017 m/s (0.07 in./s) and 112 dB. An engineer's evaluation was requested.

Report No. 5, December 12, 2019

In a follow-up to Report no. 4, a summary of the monitoring data at the neighboring residence and the complainant's residence was provided. An engineer's report found that all daily blasting records and vibration monitoring had complied with Virginia DMLR rules. Numerous attempts to inspect the residence were rebuffed. Based on the data available, it was found that there had been no direct causal link between the reported/alleged damage (buckled yard and deformed crawl space vent) and the blasting operations at the mine. The complaint was closed with no violations or permit modifications.

Analysis of Damage

OSMRE compiled blast log and blasting seismograph data in Excel for the review period. Both ground vibration and airblast levels were estimated based on data collected at and near the complainant's residence. The highest estimated vibration level at the residence had been 0.005 m/s (0.20 in./s) with frequencies of about 10 Hz. This was insufficient to cause any of the alleged damage, including cracks in masonry, concrete, or drywall; door settlement; floor rolling or warping; or the fallen vinyl soffit.

According to RI 8485, window breakage is the first sign of airblast damage and may occur at 140 dB. Airblast also causes midwall movements. Homes are very resistant to damage from midwall movements, but these vibrations do cause objects on the wall to rattle and move. The highest estimated airblast at the residence was estimated to be 127 dB, which carried no damage potential. Window breakage was not alleged.

A preblasting survey of the structure was conducted on October 10, 2018. Pictures of the structure's exterior were taken and descriptions were written, but none of the interior was surveyed. The survey date had been over a year before blasting began and was of little value since many changes could have taken place over that time. However, the fallen vinyl soffit and some exterior foundation cracks were observed.

Blast-induced yard subsidence was also claimed. The Dorchester and Imboden coal seams were mined in the area. The Imboden, at about elevation 597.3 m (1,940 ft), cropped on the hill above the residence. The Dorchester, at about elevation 578.6 m (1,800 ft), was mined but mine maps housed in the National Mine Map Repository indicated that mining was not carried on under the property.

Findings

After four complaint investigations through the end of 2019, the Virginia DMLR issued the following findings:

- No violations were committed and there was no need to modify vibration limits at the complainant's residence.
- Blast records were complete and critical information on the charge weight per delay in the blast reports was accurate. For many blasts, however, blast locations were in error and verification of the distance to the nearest protected structure for the purpose of scaled-distance compliance was not possible. Some blast locations plotted off the permit or were in unmined areas, presenting a possible blasting compliance issue with scaled-distance limitations.
- Scaled-distance compliance was mitigated by use of blasting seismographs at the water tank and Exeter from the start of mining. None of the blasting seismograph records exceeded Virginia DMLR vibration limits of 0.025 m/s (1.0 in./s) or 133 dB.
- The BIVDEP yielded poor vibration results because of weakness in the blast log location data and reported attendant distances to the nearest structure.
- The alluvial valley soils along Pigeon Creek and near-surface underground mines caused ground vibration frequencies to be low (about 10 Hz).
- The complainant's residence was a typical dwelling as defined by USBM RI 8507 and RI 8485 (Siskind et al. 1980; Siskind 1980) with drywall-covered interior walls. As such, the residence would respond to blasting-induced vibrations in a predictable manner.
- The maximum ground vibration estimated at the complainant's residence was 0.005 m/s (0.20 in./s) at about 10 Hz. At frequencies below 20 Hz, vibration levels would need to exceed 0.019 m/s (0.75 in./s) to damage drywall or other building materials,
- The maximum estimated airblast level at the complainant's residence was 127 dB. Cosmetic cracking would not begin until airblast levels reached about 133 dB for plaster-on-lathe structures. Window breakage might occur at levels above 140 dB.
- The complainant's property was not undermined, and movement or unevenness of the ground was not due to subsidence or blasting.

Investigator's Report

Within the boundaries of reasonable engineering and blasting certainty, and subject to change if additional information were to become available, the investigator (explosives/blasting engineer) concluded that blasting conducted by the drilling company had not generated ground vibration or airblast levels in excess of the VA DMLR limits or the recommended limits established by USBM at the complainant's residence. The investigator determined that blasting vibrations had not been contributing factors to the alleged damages at the residence or to the subsidence in the yard.

Lessons Learned

To understand the complaint resolution process and summarize its important components, the research team reviewed two OSMRE reports as well as articles, conference proceedings, reports, and information posted on websites to add value to its findings. The following paragraphs summarize the lessons learned:

A basic understanding of blasting vibration and its effect on nearby structures is needed by personnel responsible for evaluating damage claims. These claims generally involve issues of negligence in tort. The fundamentals of blasting, seismology, acoustics, and structural engineering are needed for successful dispute resolution and prevention of negligence suits, as in many tort cases. Furthermore, technical information and jargon used to predict and determine the effects of blast vibration, which are beyond most people's understanding, complicate the response to complaints. For example, the two case studies presented here used technical terms such as peak particle velocity, frequency of ground vibration, scaled distance, and decibels of airblast that may not have been understandable to the complainant. Cooperation among local authorities and mines/blasting companies could help complainants as well as local residents generally understand potential effects of nearby mine activity on their property,which could prevent tort of negligence claims.

During the dispute resolution process in both case studies, blast logs were reviewed for accuracy; ground vibration, airblast levels, and frequency were estimated at the complainant's residence; the structure type was evaluated; preblast surveys were reviewed; and damage potential was determined. In both case studies, the complainant's residence was a typical dwelling as defined by USBM RI 8507 and RI 8485, with drywall-covered interior walls. As such, the residence responded to blasting-induced vibrations in a predictable manner and vibrations did not exceed current limits. However, without proper knowledge of terms and facts, local residents tend to file a complaint once they see damage to their property and seek monetary compensation, regardless of whether the damage is due to mine-blasting activity.

Construction materials and construction methods correlate with structural responses to blasting impacts. When ground vibrations are within the frequency range of 4–12 Hz, residential structures may resonate. According to USBM, at frequencies over 40 Hz a structure will not resonate and nearly 0.051 m/s (2.0 in./s) of ground vibrations are needed to cause threshold/cosmetic cracking in drywall and plaster. Under 40 Hz, cracking may occur down to 0.0127 m/s (0.5 in./s). More than 0.076 m/s (3 in./s) of ground vibration is needed to cause cracking in concrete or masonry Crawford and Ward (1965). Airblast damage is prevented at levels below 133 dB. Wall hangings and shelf knickknacks vibrate and noise from any blasting activity is annoying.

The primary tool for ground vibration control and compliance used by blasters is square-root scaled distance. The distance from the blasting source to the monitoring site is important because the greater the distance, the greater the attenuation of the vibration energy (Connolly 2018). Vibration levels depend on the relationship between charge weight per delay and distance to a given point (scaled distance). Accurate distances are vital in determining the allowable charge weight in blast design to control ground vibrations and airblast because both decrease with increasing distance. The case study report found that many blast locations were in error and subsequent verification of distance to the nearest protected structure for scaled-distance compliance was not possible. The mines were able to provide blasting seismograph-monitoring data to supplement blast logs for compliance.

Surface mine blasting rules have specific requirements for all coal mine blasting within the state West Virginia. Distributing these requirements to local property owners would be beneficial as would a revised policy on blast vibration levels and structure distance from a blast site.

Conclusions

The reports from the West Virginia and Virginia case studies illustrate the technical information to be reviewed during investigation of blasting effects on nearby structures. Complaints may initially appear legitimate, but after thorough review of blast logs, blasting seismograph data in terms of ground vibration and airblast; estimates of vibration levels at a structure; determination of structure type; and verification of compliance with local regulations, most claims are determined to be unfounded. In each case study, the property owner filed a complaint for monetary compensation for damages to his property by blasting. The OSMRE explosives/blasting engineer and state inspectors presented their findings. and found no blasting-related damages to the complainant's residence in either case.

This study highlights the importance of reviewing blasting records, site conditions, and structure characteristics not only to successfully defend against damage claims but also to prevent negligence suits as in many tort cases. Recommended actions include

1. Review of blast records, charge weight per delay, distance, and confinement.
2. Review of blasting seismographs, ground vibration, and airblast intensities and frequency.
3. Determination of spatial relationships between blast locations, monitoring locations, and structures.
4. Determination of vibration levels at damage claim locations in terms of PPV, frequency, and dB.
5. Evaluation of structure condition to determine if it is typical of structure condition previously researched. For example,
   a. If the structure is typical, a finding of no damage is appropriate at vibration levels below 0.0127 m/s (0.5 in./s) and 133 dB.
   b. If the structure is typical, ground vibration frequency and construction materials (i.e., plaster-on-lathe, drywall) at ground vibration levels above 0.0127 m/s (0.5 in./s) must be evaluated to resolve a claim.
   c. If the structure is atypical (i.e., historical, unique) structure response measurements may be necessary to evaluate damage potential.

The lessons learned from this study emphasize the need for mining companies to identify their permit areas in relation to nearby residential structures and to consider structure type for appropriate vibration limits and damage prevention. Foremost is the need to conduct monitoring with blasting seismographs to adequately evaluate and minimize tort claims.

Data Availability Statement

All data used during the study are available from the corresponding author by request.

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