Explosive Operations for Constructing a Tunnel Based PCB Collection System

By Patrick McAlinden, James McAlinden, Daniel Frost, and Gerard McAlinden Sr.

In an effort to recover Polychlorinated biphenyls (PCB's) that had leached into bedrock below the Hudson River in Upstate New York, a shaft and tunnel complex was designed that would allow installation of inclined and vertical wells into the zones of contamination to recover PCB's by gravity. A joint venture of Merco Inc., of Lebanon, NJ, and Obayashi Corporation, of San Francisco, CA, was awarded the contract for constructing the first Tunnel Drain Collection System (TDCS) in the world. Conventional drill and blast techniques were the most economical method to construct the project but due to the presence of PCB's and community concerns, innovative drill and blast practices were needed.

Introduction

In Upstate New York PCB contamination has been an ongoing environmental concern for many years. In an effort to mitigate this contamination two large projects were proposed. Dredging of the Hudson River to remove PCB's that are present and constructing a Tunnel Drain Collection System to intercept PCB's before they can migrate into the river from the source of contamination. This article addresses the construction of the Tunnel Drain Collection System, the unique challenges associated with working in contaminated strata, and complying with rigid blasting guidelines and oversight.

The project was very high profile with oversight from the Environmental Protection Agency, Occupational Health and Safety Administration, New York State Department of Environmental Conservation, New York State Department of Labor, New York State Department of Health as well as multiple levels of oversight from the owner's representatives. The health and safety of workers and the public was the number one priority for all involved.

The Tunnel Drain Collection System consists of an access shaft 24 feet (7.31m) in diameter and 220 feet (67m) in depth with the bottom 24 feet (7.31m) of the shaft belled out to a diameter of 42 feet (12.8m) (see **Figure 1** and **Figure 2**). The tunnel consists of three 10 feet (3.05m) diameter horseshoe segments. Tunnel 1 is 325 feet (99.1m) long and ending with a 24 feet (7.31m) diameter work room (WR – 1). Tunnel 2 begins at this work room at 90 degrees to the left of tunnel 1 and extends 293 feet (89.3m) ending with another 24 feet (7.31m) diameter work room (WR-2). Tunnel 3 begins at WR-1 heading at approximately 45 degrees to the right of tunnel 1 and extended 350 feet (106.7m) ending with another 24 feet (7.31m) diameter work room (WR-3) (see **Figure 3**).

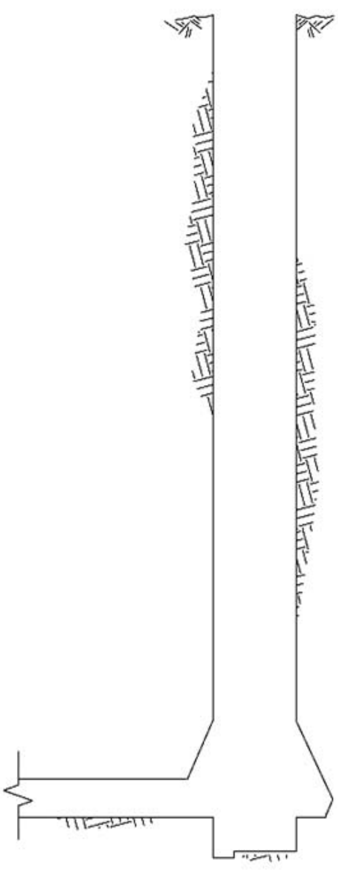

Figure 1. Elevation view of the TDCS Shaft.

Blasting was the only practical way to construct the Tunnel Drain Collection System but the presence of PCB's in the work zone, rigid blasting limitations and public concern presented formidable challenges.

Hazardous Waste Operations and Emergency Response Standard and PCB's

Due to the nature of the contamination on this project, all blasting operations needed to be carried out under OSHA guidelines for Hazardous Waste Operations and Emergency Response Standard HAZWOPER (OSHA, 1986). Prior to commencing excavation and contrary to typical shaft construction, the area was graded so water would enter the shaft and not leave the site. An exclusion zone was established around the perimeter of the excavation site and any work carried out in this zone had to be performed under HAZWOPER guidelines.

Polychlorinated biphenyls or PCB's, were used as coolants and insulating fluids (dielectric fluids) for transformers and capacitors as they are chemically very stable, have a very high flash point, and have a specific gravity higher than water, which allows it to displace moisture in these components. These same attributes also make PCB's a persistent environmental contaminant. The paths of possible contamination to humans are ingestion, skin absorption, and aerosolized inhalation.

Prior to commencing work in the exclusion zone all workers were given a thorough health screening and baseline blood work. A 40 hour training course was provided to all workers per OSHA guidelines. A written health and safety plan was distributed to all workers. Based on levels of contamination present it was determined that personal protective equipment (PPE) to be used in the exclusion zone would include: hard hats, safety glasses, viton boots and gloves, and polycoated tyvek suits. During drilling operations workers were also required to wear full face respirators to prevent aerosol inhalation exposure (see **Figure 4**). Prior to entering the exclusion zone, all of this gear needed to be in place. To prevent ingestion, eating, drinking, and tobacco use was not permitted in the exclusion zone. A decontamination trailer was set up for use when leaving the exclusion zone. Decontamination consisted of thoroughly washing reusable PPE with soap and water and one time use products were disposed of in hazardous waste disposal dumpsters. Once PPE was completely removed, hands were thoroughly washed as well. Anything that entered the zone had to be decontaminated or disposed of prior to leaving the decontamination trailer.

Air, water and spoils samples were regularly tested for levels of PCB contamination to ensure that workers were adequately protected.

These measures were very effective in protecting the health and safety of all the workers. Upon completion of the project exit health screenings and blood work were all clear of any PCB's.

Figure 2. Elevated view of the TDCS Shaft collar.

Figure 3. Plan view of the TDCS Shaft and Tunnels.

Figure 4. PPE during drilling operations at the TDCS.

Drilling and Blasting Challenges under HAZWOPER

As anything that entered the exclusion zone had to be decontaminated before leaving, this presented some logistical challenges for the drilling and blasting operations. For efficiency, it was determined that the best course of action in drilling operations was to leave the equipment in the exclusion zone until completion. All spoils removed from the excavation had to be stored in concrete bins and tested. Based on levels of contamination the spoils could be stock piled on site or, if levels were high, trucked to a hazardous materials disposal site. An additional bin was constructed for storage of drill rigs, steel, and excavation equipment. This eliminated the need to continually decontaminate the equipment with each excavation cycle. If maintenance was needed on equipment it would be decontaminated and moved from the exclusion zone for service.

Explosives brought into the exclusion zone were also subject to the decontamination requirements. Cardboard boxes do not hold up well to soap and water. To prevent migration from the exclusion zone to the powder truck and magazines, just enough explosives were brought into the exclusion zone for each blast. Clean boxes were stored outside the exclusion zone so any excess material could be safely transported back to the magazines. All other packaging materials were disposed of in a hazardous materials dumpster in the exclusion zone. Tamping poles and buckets for stemming were stored with the drilling equipment so they did not need to be decontaminated. Powder punches and hand tools were also decontaminated.

An unexpected problem arose with the use of dual delay detonators which were used during shaft blasting. PCB's are very slippery and when they are present in the shaft they will lubricate the shock tube. Great care needed to be taken when connecting to the surface delay, as this lubrication made it very easy to cross tubes in the bunch block. As each delay was tied up the blaster would visually check to make sure there were no crossed tubes.

These measures successfully stopped the migration of contamination. At the conclusion of the project, swabs randomly collected from the powder truck and magazines found no PCB's present.

All of these safety precautions slowed production considerably compared to shaft and tunnel construction in clean strata. A historical comparison to past projects of similar scope revealed a reduction in production of about 35%.

Shaft Blasting Operations

The original blasting specifications for this project were very stringent. Vibration specifications were reasonable with PPV limited to 1 in/s (2.54 cm/s) at greater than 40 Hz and varying linearly at less than 40 Hz, but the most restrictive constraint was a 120db peak overpressure limit. Also restricting the blasting operations in the job specifications was a definition that flyrock is any rock fragment thrown more that 10 feet (3.05m) from the blast. With the high powder factors associated with shaft and tunnel blasting the contractor was concerned with compliance on the overpressure restriction. The contractor hired Gerard McAlinden Sr., of Jerry Gerard Ltd., as a blasting consultant and to help with blast designs that would comply with these specifications. The contractor's consultant made several recommendations to limit overpressure, some of which broke from standard shaft construction techniques. First he suggested getting the overpressure limit raised to the Bureau of Mines RI 8485 recommendation of 133dBL (Siskind and others, 1980).

Upon exploring the possibility of increasing the overpressure limit, the owner's blasting consultant, Gordon

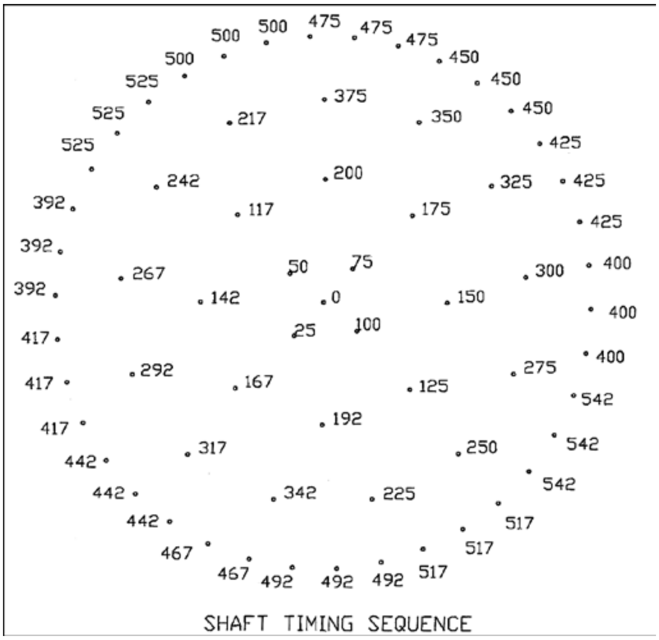

Figure 5. Shaft timing.

Shaft Blast Seismograph Results				
Blast #	**PPV (in/s)**	**PPV (cm/s)**	**Mic Peak (dB)**	**Notes**
1	0.21	0.5334	114.2	25% Test Blast
2	0.31	0.7874	119.1	60% Test Blast
3	0.8	2.032	121.8	100% Test Blast
4	0.375	0.952	119.8	
5	0.35	0.889	129.1	Test Blast - No Vari Stem Plugs
6	0.34	0.8636	127.6	
7	0.33	0.8382	124.4	
8	0.2	0.508	116.9	
9	0.19	0.4826	123.3	
10	0.205	0.5207	126.3	
11	0.265	0.6731	124.1	
12	0.19	0.4826	125.7	
13	0.145	0.3682	122.4	
14	0.16	0.4064	127.7	
15	0.1	0.254	127.2	
16	0.15	0.3809	124.3	
17	0.115	0.292	125.3	
18	0.155	0.3937	127.8	
19	0.095	0.2413	126.6	
20	0.155	0.3937	126.2	
21	0.045	0.1142	119.6	Shaft Complete

Table 1. Shaft blasting and air-overpressure measurements.

Revey, of Revey and Associates, was very cooperative in getting all parties involved with oversight to agree that 130db overpressure was a much more reasonable number. This increase was very difficult to obtain from all parties involved, and any blast that exceeded the limit would halt blasting operations until all parties approved an amended blast plan to comply with the specification.

The contractor's consultant also recommended not using relief holes in the shaft blasts and limiting the depth of each blast to 10 feet (3.05m) because the relief holes could be a path for premature gas release and contribute greatly to air overpressure. By limiting the depth of each blast to 10 feet, the need for room for rock movement was negated, eliminating a possible source of excess overpressure (McAlinden, 1955). Efficiency in production cycles was an added benefit of 10 foot (3.05m) lifts. The yardage in each blast could be excavated in a single shift, and the 10 foot (3.05m) lifts worked well with the rock bolt pattern specified.

As premature stemming ejection contributes to air overpressure the contractor's consultant suggested the use of Vari Stem stemming plugs in conjunction with 3/8 inch (18.66mm) crushed stone stemming. Two studies by Doug Bartley, of DBA Consulting, had shown that these stemming plugs contribute to stemming retention 50ms or more above unplugged holes and improve fragmentation (Bartley, 2002, 2003).

Another suggestion by the contractor's consultant was the use of a shaft cover to control flyrock and attenuate air overpressure. He designed a cover of blasting mats and steel plate that could readily be placed over the shaft by the shaft service crane in a single pick for blasting operations. The mats provided relief for gasses so as not to lift the shaft cover.

These recommendations were accepted by the contractor and per job specifications a test blast program was developed. Three test blasts were specified at 25%, 60% and 100% based on production blast weights.

The site geology consisted of three distinct layers - Upper Snake Hill Shale, Middle Snake Hill Shale, and Lower Snake Hill Shale. The compressive strength of these layers ranged from 10,000psi to 19,000psi. Bedding planes could best be described as random and folded.

Dual delay detonators were used to initiate 2 inch x 16 inch (50mm x 400mm) emulsion with one hole per 8ms period firing on production holes. Perimeter holes were fired three holes per delay and loaded with trim blasting products (see **Figure 5**). Powder factors for production blasts averaged 3 lbs/yd^3 (1.78 kg/m^3). A total of nine seismographs were used to monitor each blast, two of which monitored for overpressure. The remaining seven were installed on adjacent structures and were data linked to report blast events.

Table 1 summarizes the results from the closest seismograph for all shaft blasting. Although the data is limited, it is worth noting that all shaft blasts were fired with stemming plugs except one. Number five was the contractor's test to see if the stemming plugs were effective. As this blast approached the compliance number for overpressure no further testing was attempted. Fragmentation was excellent and spoils were rapidly handled by mini class excavators. The shaft was sunk to completion without any non-compliant blasts.

Tunnel Blasting

Prior to commencing driving tunnel, the contractor decided to continue using stemming plugs in conjunction with clay dummies in the tunnel rounds. The shaft cover was also used. Typical rounds for the 10 foot horseshoe contained 48 holes 6 feet (1.83 m) in depth. Average powder factor for each round was 4.25 lbs/yd^3 (2.52 kg/m^3) although the burn cut powder factor was much higher. Holes were fired with 14 LP nonel delay periods initiated with detonating cord (see **Figure 6** and **Figure 7**).

Holes were initially stemmed to the collar with clay dummies to help control overpressure. The plug manufacturer suggested that in this application the stemming could be reduced with acceptable results (Bartley, 2006). **Table 2**

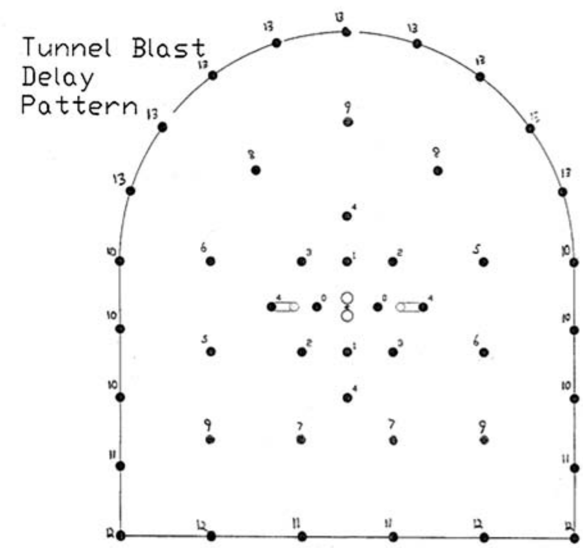

Figure 6. Typical tunnel blast design.

Tunnel Blast Seismograph Results				
Blast #	**PPV (in/s)**	**PPV (cm/s)**	**Mic Peak (dB)**	**Notes**
1	0.075	0.19	124.2	Test Blast
2	0.08	0.2032	126.4	
3	0.095	0.2413	123.9	
4	0.25	0.635	126	
5	0.315	0.801	127.1	
6	0.145	0.3683	127.7	
7	0.3	0.7619	128.2	
8	0.24	0.6069	127.5	
9	0.135	0.342	126.7	
10	0.175	0.4445	127.7	
11	0.225	0.5715	126.9	Stemming test
12	0.24	0.6096	128.2	Stemming test
13	0.17	0.4318	125.2	Stemming test
14	0.15	0.381	124.5	Stemming test
15	0.145	0.3683	124.7	Stemming test
16	0.15	0.381	124.2	
17	0.23	0.5842	126.6	
18	0.105	0.2667	125	
19	0.2	0.508	124	
20	0.13	0.3302	124.9	

Table 2. Tunnel blasting vibration and air-overpressure measurements.

Figure 7. Tying up at heading.

lists results of the closest seismograph for 20 tunnel blasts. The first 10 rounds were stemmed to the collar with clay dummies. During the next five rounds the holes outside the burn cut were gradually stemmed less each round until just one 8 inch (20.32cm) clay dummy was used. The last five blasts continued with just one clay dummy outside the burn. The project was completed with this stemming technique.

As you can see by the overpressure results, no noticeable difference was detected. There was no noticeable change in the size of muck or mucking times during this testing and subsequent production blasting.

Project Completion

Upon the completion of tunnel blasting, a permanent invert was poured in the tunnels and shaft. Twenty-one horizontal and vertical wells were installed ranging in depth from 100 feet to 300 feet. These wells are draining to a sump in the shaft that pumps to a treatment plant to remove PCB's from the water. In addition to the wells, five multi level (three sensor levels) vibrating wire piezometers from 85 feet (25.9m) to 315 feet (96m) were installed.

Conclusions

Working in and around hazardous materials presents challenges not normally faced in blasting operations. Protecting workers from exposure and preventing the migration of contaminates is paramount to these operations. These precautions are time consuming and repetitive but must be strictly adhered to for safe operations.

By limiting the early release of gases from blast events peak overpressure can be controlled. Using innovative techniques (not normally applied to shaft blasting), stringent specifications were met. Stemming plugs appear to have a noticeable effect on lowering peak overpressure although further studies for comparison would be useful.

The use of stemming plugs in underground blasting seems effective in limiting peak overpressure. The plugs also seem to reduce the required stemming necessary for good confinement. During this project, reducing the stemming in each round noticeably increased the speed on which a round could be loaded. This benefit could lead to substantial savings in underground mining applications.

References

Bartley, Douglas A., 2003, Performance Testing of the VARI-STEM 4.5" Hole Plugs, MOCAP Industries, St Louis, MO

Bartley, Douglas A., 2002, Blast Fragmentation Enhancement Using MOCAP VARI-STEM Hole Plugs, MOCAP Industries, St. Louis, MO

Bartley, Douglas A. 2006, Performance Testing of 1.25" and 1.75" VARI-STEM Plug Designs, MOCAP Industries, St. Louis, MO

McAlinden Sr., Gerard I., 1955 - , Personal Notes on Blast Performance, Unpublished

United States Department of Labor, Occupational Health and Safety Administration 1986, Regulations (Standards – 29CFR) 1910.120

Siskind, David E. et al., Structure Response and Damage Produced by Airblast from Surface Mining (USBM RI 8485) Washington, U.S. Bureau of Mines, 1980

This article was presented by the authors at the ISEE's 36th Annual Conference on Explosives and Blasting Technique in February, 2010 in Orlando, FL. This paper has been updated from its original version. The opinions and ideas expressed are not necessarily those of the International Society of Explosives Engineers or the editorial/publishing staff of the Journal of Explosives Engineering. See "The Proceedings of the 36th Annual Conference on Explosives and Blasting Technique" for full text and references for this paper.