Gas Mitigation in the Mill Creek Tunnel

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ABSTRACT

Methane gas caused an eight-month shutdown of mining operations at the Mill Creek, Phase 3, Tunnel. The gas-related shutdown occurred as the tunnel was advanced to an approximate distance of 2,700 feet, which constitutes approximately 18 % of the total tunnel length. The construction of an emergency ventilation shaft, a comprehensive program of de-gassing wells and an expanded gas monitoring system were used to mitigate the gas condition. When complete, this tunnel will be utilized to convey and store combined storm and sanitary sewage collected from a portion of Cleveland, Ohio and ten suburbs.

This paper will provide an overview of gas related remedial measures and explain how these measures were integrated into the project to ensure safe tunneling conditions.

INTRODUCTION

The Mill Creek, Phase 3, Tunnel (MCT-3) is currently under construction with planned completion in the year 2008. It is one of the largest tunneling projects undertaken by the Northeast Ohio Regional Sewer District (NEORSD) to date. The tunnel horizon is situated within the Devonian Chagrin Shale rock formation at an average depth of 280 feet. The tunnel was excavated using a two-pass method. A full face, fully shielded, Robbins, 23.8 ft diameter tunnel boring machine (TBM) was used to excavate approximalty 15,000 feet of tunnel and facilitate installation of initial supports (first pass). The final lining (second pass) consists of 12-inch thick cast-in-place reinforced concrete and integral low flow channel. A total of seven (7) shafts were constructed on the project with the excavation of the tunnel commencing at Shaft 14, and proceeding down grade to Shaft 9, the terminus shaft.

Just prior to the eight-month gas related shutdown, several unusually large plumes of methane gas entered the tunnel while mining was proceeding. Each of these occurrences required that mining operations be suspended and all personnel be evacuated from the tunnel. The first incident of gas in the tunnel occurred when the tunnel intersected Down-Hole No.1 (Figure 1) on August 9, 2004. However, due to the frequency and volume of subsequent gas occurrences, the decision was made by the District (NEORSD) to suspend mining operations. Additional steps were then taken to mitigate the gas including drilling de-gassing wells, installing a comprehensive gas monitoring system and constructing a new 14-ft diameter ventilation shaft. Shortly before the suspension of mining operations, the Contractor Kassouf, Murray Hill, Mole & Kenny, a Joint Venture (KMM&K) attempted to mitigate the gas occurrences by installing an additional blower and bag line that evacuated air from the vicinity of Down-Hole No. 1 and discharged it at Shaft 14. This improvement proved insufficient in quickly dissipating gas occurrences.

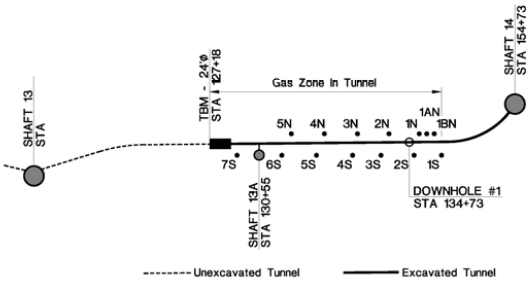

FIGURE 1 Location plan

NATURAL GAS IN CHAGRIN SHALE

Although not frequent, methane gas has been encountered in previously mined tunnels within the Chagrin Shale Formation. The subsurface investigations confirm that low levels of methane could be encountered in this rock formation and that the gas appears to be confined to openings along joints and bedding planes. It is also known that shallow gas wells in the project region produce some amount of gas for domestic consumptions.

POTENTIALLY GASSY TUNNEL

A tunnel is classified as potentially gassy if either of the following circumstances are anticipated or occur:

- When air monitoring shows 10 % or more of the lower explosive limit (LEL) for methane or other flammable gases, measured at 12 inches (304.8 mm) from the roof, face floor or walls in any underground work are present for more than a 24-hour period.
- When the geological formation or history of the area indicates that 10% or more of LEL for methane or other flammable gases is likely to be encountered in such underground operations.

The MCT-3 Contract Documents classified this tunnel as "potentially gassy". The Contract Geotechnical Baseline Report (GBR) states that quantities of natural combustible gases (primarily methane) under pressure shall be anticipated in the shafts and tunnels. The GBR further stipulates that encounters of gas requiring temporary suspension of construction operations should be expected.

It is important to note that the construction equipment utilized to mine the tunnel met the OSHA requirements for a potentially gassy tunnel.

GAS EMISSIONS CAUSING WORK SUSPENSION

On April 2, 2004, prior to the start of the mining operations, gas was encountered at a depth of 230 feet while the Contractor was drilling a down-hole along the tunnel alignment (Down-Hole No.1), Figure 1. It took approximately thirty hours for high-pressure gas to dissipate from the down-hole. Because gas was frequently encountered during previous subsurface investigation borings, there were no immediate concerns. The downhole was left open to vent any additional gas that developed. The first incident of gas inflow in the tunnel occurred on August 9, 2004, when the tunnel reached its intersection with Down-Hole No. 1. On that and subsequent dates, gas was released into the tunnel in a sudden cloud and under pressure, which quickly overwhelmed the ventilation system. The frequency of gas emissions into the tunnel continued to intensify between August 19 and 26, 2004, causing several tunnel evacuations. It is important to note that these gas emissions did not cause tunnel conditions to meet OSHA's requirements for a gassy tunnel. Evacuation of the tunnel is required when the lower explosive limit (LEL) reaches 10%. Based

on the numerous readings and high LEL levels during this period, the decision was made to suspend mining operations on August 30, 2004. At the time of shutdown, the tunnel was advanced to Station 127+18, an approximate distance of 2,700 feet from Shaft 14. The location of the TBM at the time of shutdown is illustrated in Figure 1.

The following table demonstrates the frequency of emissions, which eventually lead to a decision to suspend mining operations (see Table 1).

TABLE 1 Summary of Gas Emissions in Tunnel

Date	LEL %	Location of Gas Detection	Remarks
April 2, 2004		At downhole Sta.134+73	Rapid gas discharged for 30 hours
August 9, 2004	118	At tunnel heading Sta. 134+73	Brief tunnel evacuation
August 19, 2004	146	At Station 134+73	Tunnel evacuated; gas clear in one hour
August 20, 2004	123	At Station 128+00	Tunnel evacuated; 3-hour shut down
August 20, 2004	195	Behind the TBM-Station 129+13	Tunnel evacuated-shift ended
August 23, 2004	65	Behind the TBM-Station 129+13	Ceased mining to increase ventilation
August 26, 2004	76	At Station 134+73, hand-held monitor	Tunnel evacuated; gas clear in one hour
August 30, 2004		TBM at Station 127+18	Start of eight-month shutdown
April, 2005		TBM at Station 127+18	Resumption of mining operation

GAS MITIGATION MEASURES

Initial Ventilation Capacity

Initially, the tunnel ventilation system in the MCT-3 Tunnel consisted of a series of fans and ducts. This arrangement pulled air from the tunnel face and exhausted it to the ground surface. The primary exhaust line was a 60-inch diameter bag line and the secondary exhaust was a 30-inch steel duct, which together provided a total of 50,000 cubic feet per minute (CFM) of tunnel ventilation. Prior to tunnel shutdown, the Contractor upgraded the tunnel ventilation by introducing another 60-inch diameter bag line on August 20, 2004. This provided an additional 30,000 CFM, totaling 80,000 CFM in tunnel ventilation capacity.

Required Additional Ventilation Capacity

Based on initial readings of LEL levels at various locations in the tunnel and knowing the existing ventilation rates, we were able to estimate a sudden peak methane inflow of 3,000 CFM. These estimates indicated that an additional ventilation capacity of 300,000 CFM was needed to safely dissipate additional occurrences of gas of similar volume.

Degassing wells

In order to allow the release of gas from the bedrock and provide data on gas conditions along the tunnel, a total of fourteen (14) de-gassing wells were drilled in the area of the potential gas source, from Station 135+75 to 129+75. As illustrated in Figure 1, the relief wells were located on each side of the tunnel at 50-ft centers and were drilled to an approximate depth of 500 feet. The top portion of each well, between the ground surface and Chagrin Shale contact, was cased and grouted, while the remaining portion of each well within the Chagrin Shale was left open to allow gas and water to flow into the well, as illustrated in Figure 2. Each well was furnished with a pump to maintain the groundwater level at a depth of approximately 140 feet below the tunnel grade.

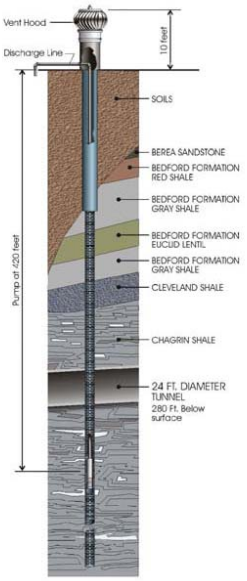

FIGURE 2 Profile of degassing well

Figure 3 shows a typical record of gas inflow into the borehole during drilling operations. From these records, most wells commonly show gas emissions occurring below a depth of 300 feet, and the tunnel grade. Initially, methane was detected at or above 100% of LEL in each of the 14 wells. However, shortly after completion of drilling operations, gas emissions into the de-gassing wells subsided considerably, with the majority of the wells discharging methane gas generally below 5% of LEL. Examples of this can be found in Figure 4. All 14 wells remained in operation during subsequent tunnel mining and lining activities.

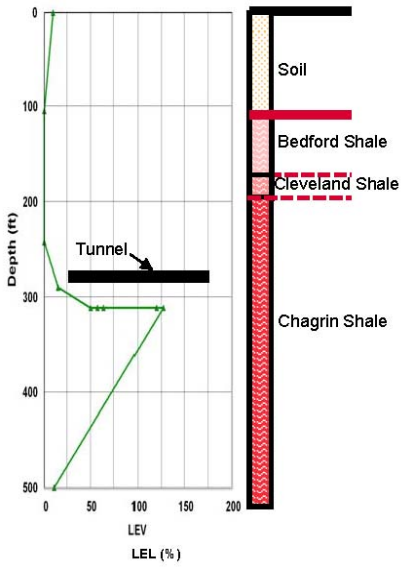

FIGURE 3 Typical drill log of degassing well

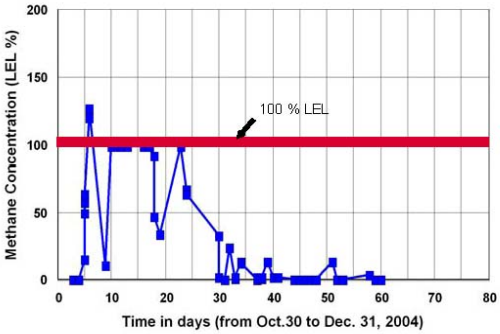

FIGURE 4 Typical gas discharge during shutdown

Measures to Enhance Ventilation Capacity

In order to meet the ventilation criteria outlined in the preceding paragraphs, plans were developed to increase the ventilation capacity of the tunnel. The measures taken would need to be capable of quick dissipation of a peak methane inflow of 3,000 CFM to a safe level (less than 10 % LEL). Part of the solution was for the Contractor to retain a specialized gas mitigation Consultant. KMM&K retained Weir International Mining Consultants, Inc.

(WIMC) to provide an independent evaluation of the gas issue. Based on the recommendations of WIMC, the Contractor proceeded to increase the ventilation capability from the existing 80,000 CFM to 300,000 CFM. This was accomplished by constructing a new 14-ft diameter ventilation shaft equipped with four 75-hp blowers. New ventilation Shaft 13A was located about 400 feet downgrade from Down Hole No. 1 and about 300 feet behind the TBM cutter head (see Figure 1). It was determined that this additional ventilation shaft, with the help of baffles in the tunnel, would effectively dilute any methane inflows to below shutdown levels, and thereby satisfy the requirements for safe resumption of tunnel operation. Baffles were installed in the gas zone to create a turbulent air stream, thereby ensuring that a concentrated plume of gas entering the tunnel is quickly mixed with air. This additional ventilation feature reduces the possibility of gas layering in the crown of the tunnel in the event of new gas emissions. The shaft was constructed off line of the tunnel and was connected to the main tunnel through a 10-ft long adit, (see Figure 5). Around-the-clock (6 days/week) operations were implemented to construct the shaft as quickly as possible.

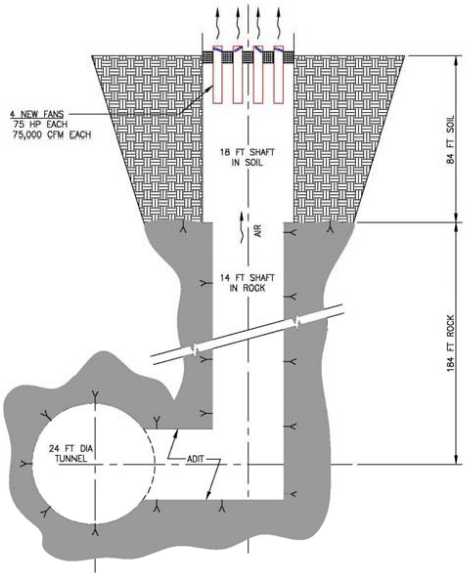

FIGURE 5 Ventilation shaft 13A

Tunnel Monitoring System

As part of the gas mitigation program, the tunnel was equipped with an upgraded gas monitoring system to continuously read and record methane levels in the tunnel. New gas monitoring instrumentation, in addition to the existing monitors, was installed in three areas as indicated below.

1. Five (5) stationary gas monitors were installed in the area of the suspected gas source, about 18 feet above the tunnel inverts.
2. Two (2) new sensors, in addition to the existing three (3), were installed in the cutting and gripper area of the TBM.
3. Two (2) new sensors were installed at the rear of the TBM trailing gear.

The function of the new monitors was to provide enhanced gas detection and immediate shutdown of the TBM upon a 10% LEL reading. Data from the instruments was recorded at a central location on the Shaft 14 Site.

Tunnel Maintenance During Shutdown

During the shutdown period maintenance crews entered the tunnel on a daily basis. To ensure their safety, the Contractor developed entry procedures on the presumption that the gas was still present in the tunnel. The maintenance staff exercised the mining equipment for short durations each day to ensure its readiness for resumption of mining operations. The TBM cutter head was advanced forward and backward and rotated to ensure that the bearings and hydraulic systems remained in good operating condition. The conveyor system was operated daily to keep the bearings lubricated and maintain belt flexibility.

Resumption of Mining Operation

Full scale mining operations resumed in April 2005. Tunnel excavation proceeded by advancing the tunnel heading at an average rate of 200 feet per week and was completed in January, 2006. While driving the remaining 12,300 feet of the tunnel, there were no further occurrences of methane gas. However, the readiness for action was required while mining was in progress. The ventilation system and de-gassing wells properly performed their intended function. The monitoring equipment and ventilation system remained in place throughout the mining operation.

Tunnel Retains its Potentially Gassy Status

Although the gas occurrences were encountered while conducting mining operations, the tunnel continued to meet the OSHA criteria for potentially gassy, therefore, reclassifying the tunnel as gassy was not required.

A tunnel is classified as "gassy" if air monitoring discloses 10% or more of the lower explosive limit (LEL) for methane or other flammable gases, measured at 12 inches (304.8 mm) from the roof for three consecutive days. In such cases additional measures, such as elimination of the ignition sources, posting a sign at tunnel entrance indicating a gassy tunnel, prohibiting smoking, and maintaining a fire watch during hot work, would be required as a minimum.

CONCLUDING REMARKS

Excessive gas occurrences in MCT-3 tunnel resulted in work suspension and implementation of comprehensive remedial measures to mitigate the gas. These measures required degassing wells, a ventilation shaft and an expanded gas monitoring system in the tunnel. Even though the sudden gas occurrences temporarily exceeded 10% of LEL, the specified potentially gassy tunnel condition remained in effect throughout the tunnel construction. Much of the success for gas mitigation measures can be attributed to timely response and innovative planning by the project team members from NEORSD, MWH, PBQD, KMM&K and WIMC. This contributed to the safe completion of the mining operation.

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