The Application of Shotcrete in Shafts

WORK PREPARATION AND CONSTRUCTION BASED ON VARIOUS PROJECTS IN CENTRAL EUROPE

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The construction of all kinds of shotcrete shafts is recently very popular in Central Europe. Shafts are needed in combination with infrastructure projects, power plants, and energy and water distribution and treatment. A few of the specific uses of shafts include: ventilation, emergency evacuation, surge chambers, water transport, and pipe jacking or drop shafts in waste water handling.

Shotcrete placement in shafts requires precise work preparation and a well thought-through choice of spraying method to ensure an optimized construction process. This process and the final execution are illustrated below through several different case studies.

SHOTCRETE PLACEMENT

Depending on diameter and depth of the shaft, shotcrete gets applied either manually or by remotely manipulated nozzling equipment. Three different types of shotcreting methods are commonly used to support the excavated rock or soil surface: Dry-mix, semi-dry, and wet-mix shotcrete. Each of these methods has certain characteristics and needs to be selected based on the specific circumstances and conditions of the project at hand.

DRY-MIX SHOTCRETE

One decisive advantage of dry-mix shotcrete is the small equipment footprint on the construction site compared to the other methods. Particularly in densely populated urban areas and steep mountainous locations, storage of oven-dry shotcrete material in tower silos can avoid the constant traveling of concrete delivery vehicles and can be filled in large batches.

The process is particularly advantageous for narrow shafts and, in general, projects where only small and unpredictable quantities are used or where the use of ready-mix delivered concrete is not economical. Normally, spraying rates of up to 5 yd^3/hr (4 m^3/hr) are achieved. To reduce dust formation and rebound, it is absolutely necessary to use a pre-dampening unit.

SEMI-DRY SHOTCRETE

Semi-dry shotcrete is a variant that is rarely used today, although it has some significant advantages. The concrete itself has a similar composition to wet sprayed concrete, but the concrete materials are only partially wetted (similar to moisture levels we would see in our aggregate sources of 3 to 5%) and has water added at the nozzle during the spraying process. Essentially, this also makes sense for narrower shafts, as high spraying rates cannot be achieved here either (up to 8 yd^3 /hr or 6 m^3/hr) — depending on the size of the pump). Two of the major advantages over dry-mix shotcrete are the lower rebound factor and the significantly lower dust generation. Further, it is particularly suitable for use if a mixing plant is available on site, as it can be easily produced.

WET-MIX SHOTCRETE

In contrast to the previous variants, wet-mix shotcrete is mainly sprayed by a mechanical system of nozzle manipulation, and significantly higher spraying rates (up to 33 yd^3/hr or 25 m^3/hr) can be achieved. Dust formation and rebound can also be significantly reduced when compared to the dry processes. Due to the working space of the spraying manipulator and the cost-effectiveness of larger volumes of concrete, the use of this method usually only makes sense for larger shaft diameters.

CASE HISTORIES

18 FT (5.5 M) DIAMETER AND 279 FT (85 M) DEPTH

PROJECT DESCRIPTION

A good example of the use of shotcrete in deep and narrow shafts is the ventilation shaft of a 2.2 mi (3.6 km) long road tunnel in the southern German Alps. The single-tube road tunnel with a parallel rescue tunnel is ventilated via a false ceiling and a connected ventilation cavern. The exhaust air is then extracted out of the cavern into the open air via the ventilation shaft. The shaft itself was sunk from the surface to a depth of 279 ft (85 m) using an excavator and blasting with an excavation diameter of 18 ft (5.5 m). The site staging area for the shaft was located about 328 ft (100 m) higher than the north portal of the main tunnel on the mountainside and could be reached via a 1,640 ft (500 m) long temporary access road. Depending on the geological conditions, between 6 and 12 in. (150 to 300 mm) of shotcrete support with mostly single-layer welded wire fabric (WWF) reinforcement was applied. This is equivalent to an area of almost 16,000 ft^2 (1,500 m^2).

SELECTION OF THE SPRAYING METHOD

Due to the very cramped location, the decision was made to apply a semi-dry shotcrete manually. This was mainly due to the small quantities required for the individual work steps (usually less than 4 yd^3 [3 m^3]), which meant that the concrete mixer's delivery of about 9 yd^3 (7 m^3) could be produced over several hours. Another decisive factor was the possibility of having shotcrete on site ready-for-use while the excavation was going on. The difficult and potentially quickly changing ground and groundwater conditions required shotcreters to be able to apply shotcrete on short notice.

CONSTRUCTION WORKS

Work began in mid-2020 with the construction of a 20 ft (6 m) deep pre-cut with soil nail supported shotcrete and the site staging area. The uppermost 184 ft (56 m) were excavated with advance support using metal sheet piles, while the section below 184 ft (56 m) was completely

Fig.1: ventilation shaft from the excavation pit

excavated by drill and blast. Therefore, a 3.5-ton mini-excavator was selected which could be equipped with a drill attachment and hydraulic hammer. Due to the required rope length and flexibility, a 130-ton (118 tonnes) telescopic crawler crane (manufactured by Sennebogen) was used for the vertical lifts in and out of the shaft.

The concrete was produced in the site's mixing plant, located at the portal of the main tunnel, approximately 1.2 mi (2 km) from the shaft site, and temporarily stored on the site in a concrete handling hopper. An Aliva 262 rotary dry-mix shotcrete gun was used as the spraying device, which was supplied with compressed air from an Atlas Copco GA75 compressor.

To transport the concrete, a steel pipe (2 in. (50 mm) diameter) was attached to the wall. Particular attention was paid to adequate fastening, as the heavy weight of concrete and pipe over 279 ft (85 m) posed a serious risk to personnel. The supply lines were extended at regular intervals, usually every 16.5 ft (5 m).

The shotcrete was delivered by the electric rotary gun positioned at the surface with compressed air through the steel pipe to the nozzle. Water and accelerator were then added by the shotcreter in the shaft. The rate at which the accelerator was added was approximately 5-8% to achieve the required early strength development curve of J3 (see Austrian Guideline for shotcrete [1] and European Standard [2]). Warm water was used to kick-start the hydration process during the cold winter weather.

Fig.2: Feeding the Alivia-Pump with shotcrete

The use of semi-dry shotcrete also offered occupational safety and economic advantages, since the amount of dust and rebound is significantly reduced compared to dry-mix shotcrete. Employees were equipped with powered air purifying respirators and a ventilation concept was designed to suit the conditions. The mandatory communication between gunman and shotcreter was ensured by radio.

The average spraying rates achieved were 2 to 2.6 yd^3 (1.5 to 2 m^3) per hour (incl. set-up time).

Fig.3: Shotcrete application inside the shaft

THICKNESS CONTROL

A comparison of the delivered and installed shotcrete quantities was carried out as part of the post-construction evaluation process of the shaft excavation. The quantities delivered were evaluated with the help of the batch plant delivery slips. The installed quantities were established using laser scanner images. Determining the difference between the scan of the finished shotcrete surface and the scan of the excavated ground confirmed that approximately 30% of additional shotcrete was needed to fill overexcavation. This in addition to approximately 20% of rebound.

16.4 FT (8.8 M) DIAMETER AND 98 FT (30 M) DEPTH

PROJECT DESCRIPTION

The rescue shaft of the Füllbach tunnel, a single-track railroad tunnel near Coburg in Germany, has a depth of 100 ft (30 m) and serves as an escape route from the 0.7 mi (1.1 km) long main tunnel. With an excavation diameter of just under 30 ft (9 m), the available space allowed the use of more powerful machines. The excavation here was carried out entirely by drill and blast with subsequent shotcrete support. The primary lining consisted of a two-layer shotcrete shell with a thickness of 7.9 in. (200 mm) and a double-layer of WWF reinforcement. The total shotcrete surface area was approximately 9,000 ft^2 (815 m^2).

SELECTION OF THE SPRAYING METHOD

This meant that 18 yd^3 (14 m^3) of shotcrete were required per excavation round of 4.5 ft (1.3 m), which was batched by the site's on-site batch plant and delivered to the shaft location by regular concrete delivery trucks. Due to the high quantity required per excavation round and the relatively large shaft diameter, the decision was made to use remotely manipulated nozzles for shotcrete placement.

CONSTRUCTION WORKS

Once the site staging area was set up and the shaft head ring constructed, the shaft sinking could begin. A single-boom drilling rig was used for the necessary drilling work. The rig and muck boxes were lifted in and out with the help of a 60-ton (54 tonne) mobile crane. The loosened material was excavated using an 8-ton (7 tonne) compact excavator. For the shotcrete application, a Normet AL-503 spraying manipulator was used, which is characterized by its compact design and long reach of up to 26 ft (8 m). The concrete was supplied using a Sika-PM702 concrete pump. The rapid-set accelerator and compressed air were added at the nozzle. With the system used, spraying rates of up to 20 yd^3 (15 m^3) per hour could be achieved.

Fig.4: Normet spraying manipulator in action

42 SHAFTS WITH 11.2 FT (3.4 M) DIAMETER

PROJECT DESCRIPTION

Due to ongoing problems with wastewater drainage during heavy rainfall events, a new collector sewer is currently being driven under the city of Vienna, Austria. The existing sewer, which is too small, discharges wastewater into the Wien River during storm induced overflows, causing serious environmental problems in Austria's capital. The construction of the new Wiental collector sewer has a total length of 5.4 mi (8.6 km) with a diameter of 11.8 ft (3.60 m) and will be excavated entirely by a tunnel boring machine (TBM). To connect the adjacent existing sewers and provide access and rescue options, a total of 52 shafts will be constructed along the course of the sewer. 42 of these shafts will be excavated using sequential excavation method (SEM) type shaft construction in soft ground with shotcrete support. Depending on the geological conditions, soil improvement is carried out at some shaft locations using jet grouting. The shafts themselves have a very small excavation diameter of just under 11.5 ft (3.5 m) and are up to 69 ft (21 m) deep. The primary lining is carried out with a shotcrete shell up to 12 in. (300 mm) thick and one to two layers of WWF reinforcement. A total of 75,000 ft^2 (7,000 m^2) of shotcrete will be installed. After completion, each shaft will have a 12-in-thick (300 mm) final lining and the respective interior installations such as sewer connection pipes and access ladders.

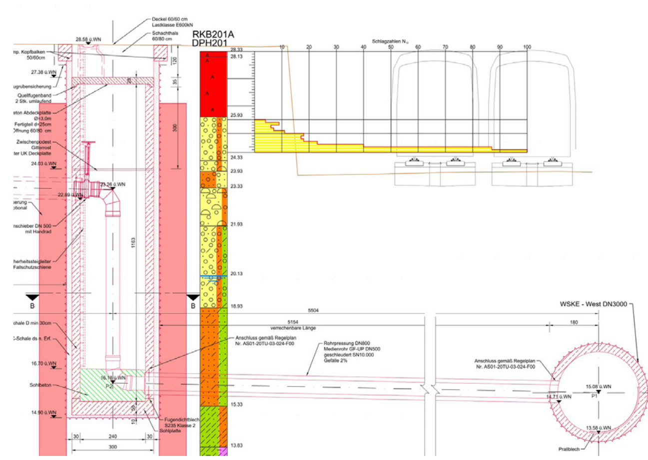

Fig.5: Section through the transfer shaft with connection to the collector sewer

CURRENT STATUS OF WORK PREPARATION

With construction starting in April 2024, work is currently concentrating on the construction of the TBM launch pit and work preparation for the construction project. Initial considerations have already been made regarding the excavation of the shafts. Excavation is planned to be carried out using an excavator positioned at the surface equipped with a telescopic boom and hydraulic grab bucket. Corrective excavation works at the bottom of the shaft will be done using a mini excavator. A mobile crane will be used for logistics and to lift equipment in and out. For schedule purposes, a total of three equipment sets will be necessary to be able to work at several shafts concurrently. Starting with one shaft at a time in the initial phase, it is planned to construct three shafts simultaneously during later stages.

SELECTION OF THE SPRAYING METHOD

What is both interesting and challenging about this project is the large number of similar shafts with very small excavation diameters. Furthermore, the size of the individual site staging areas is very limited due to the inner-city location and little room to maneuver. With a required shotcrete quantity of less than 4 yd^3 (3 m^3) per excavation round and the difficult access situations, there is still discussion as to whether dry-mix or wet-mix shotcrete will be used.

Due to the nearby residential buildings and busy roads, one of the biggest concerns is the potentially large amount of dust generated during dry-mix shotcreting. On the other hand, wet shotcreting is not the most economical solution due to the small quantities required and the limited space available. Furthermore, wet-mix shotcrete has to be delivered by a ready-mix delivery vehicle every time, whereas oven-dry shotcrete materials can be stored in large silos on site and is available at all times. The final decision will be made as part of the spraying tests at the first shaft. During this time, the machine concept will also be further optimized.

Special attention will be paid to the relocation of the construction site equipment, as a lot of working time can be saved here due to the numerous relocation processes from one excavated shaft to the next.

Due to the very cramped working conditions in the shaft with only 12 ft (3.6 m) diameter, the shotcrete will be applied manually. Therefore an electric Aliva rotary gun (e.g. Aliva 262) will likely be used, which transports the shotcrete through the delivery hose pneumatically. The advantage of this system is that it can be used for both dry and wet shotcreting.

Conclusion

Shotcrete shafts often present unique challenges for construction projects. In many cases the construction method is different from the one used in the main tunnel (often using a TBM), presenting challenges recruiting experienced and certified personnel for the shaft works. Surface conditions at shaft locations are often tight, presenting challenges not only for material supply, muck discharge, and equipment movements, but also with regard to environmental issues like dust and noise control. Project representatives need to pay particular attention to these special circumstances early on, to be able to cope with these challenges.

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Norbert Fuegenschuh *holds a masters degree in Civil Engineering, University of Technology in Graz, Austria (1989).*

He started working for BEMO Tunnelling in Innsbruck, Austria in February of 1990, is still employed by BEMO and gathered 34+ years of experience in SEM/ NATM tunneling.

After work in the estimation department he started his on-site career filling different positions on construction sites in Germany, among others on the subway system in Munich, two SEM high speed railway tunnels between Frankfurt and Cologne and the Egge-Tunnel near Kassel in the North of Germany.

In 2001 he became the Tunnel Manager on the Russia Wharf Tunnel in Boston, MA (MBTA Silverline subway between South Station and World Trade Center) and spent the time between 2004 and 2011 in Sweden as BeMo`s Area Manager for Scandinavia. Major projects there were Tunnel Troeingeberg, a 1,100 m long high speed railway tunnel in Falkenberg, Sweden and an 8,000 m long sewer tunnel from Lerum to Partille, Sweden – both are drill and blast tunnels with extensive hard rock pre-grouting.

After his move back to the US in 2011 he started working as BEMO`s Area Manager North America and got involved in several high-ranking SEM projects, among others:

- *MUNI China Town Station, Central Subway San Francisco*
- *Cross over cavern on Regional Connector, Metro Los Angeles*
- *Quarters LRT Tunnel in Edmonton, Alberta*
- *John Hart Hydro Power Station in Campbell River, Vancouver Island, BC*
- *Plymouth Tunnel as part of the Purple Line in Silver Spring, Maryland (excavation and shotcrete final lining)*
- *Cross Passages on Purple Line extension Westside 1, Metro Los Angeles*
- *Frozen Ground Adits at 4th Street and Florida Avenue on the North East Boundary CSO Tunnel in Washington, D.C.*
- *McGill South Tunnel rehabilitation, REM in Montréal, Quebec (excavation and shotcrete final lining)*
- *Grand Central/ 42nd Street passageway circulation improvement Tunnel in New York City (excavation and shotcrete final lining)*

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Richard is working with BEMO since August 2016 – as a senior project manager being involved in different projects (Kramertunnel, Herrschaftsbucktunnel, ….) From 2016-2020 he was taking care for the success of BeMo Tunnelling in Germany – in project management for several tunnelling projects as well as in the acquisition process.

Since 2020 Richard has been responsible for the cost estimation and acquisition of tunnelling projects in the D-A-CH region (Germany – D Austria A – Switzerland CH).

The responsibilities are the acquisition of new projects, integration of young engineers in our company; to stay into contact with all stakeholders inside and outside our small tunnelling world. Private: Married, 2 boys (18&17) – interests in enjoying life, travelling and spending time with the family.