Tunnel Specific Equipment for Efficiency and Versatility – Lifting and Explosives Charging

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1. Introduction

Tunneling’s evolution through the 20th Century involved a dramatic increase in mechanization as available technologies developed. However, in many cases, the specialized needs of tunneling were not specifically addressed and instead innovative and adaptable contractors utilized available equipment (for example, construction, industrial, or mining focused) either “as is” or modified on-site to their purposes.

One early trend for tunneling in the 21st Century has been the marked increase in usage of equipment specifically designed for modern applications (referencing here non-TBM tunnels). This has ranged from the more traditional disciplines such as explosives charging and elevated staging to include scaling, concrete spraying, arch installation and utility functions.

The tunnel specific equipment offers significant benefits to their operators in terms of safety, speed and efficiency of operations and, in some cases, multi-tasking. The construction of underground infrastructure is on a significant rise and suppliers such as Normet are assertively developing technologies to keep pace. This paper discusses the above trend with a focus to lifting and explosives charging.

2. General Features of Tunnel Specific Equipment

Tunnel specific equipment is built on a carrier especially designed for the rigors and demands of a modern tunnel environment. The equipment is designed to be used continuously in harsh, wet and sometimes corrosive underground conditions where fresh air is limited and with a paramount view to the highest requirements for safety, not just for the operator specifically but also those that might be present in and around the operating equipment.

Typical features of tunnel specific equipment include:

- FOPS (Falling Object Protective Structure) approved driver’s safety cabin and operator’s safety roof in man lifting devices
- ROPS (Roll Over Protective Structure) approved driver’s cabin in all earthmoving and transportation units
- oil immersed disc brakes
- working and warning lights, especially designed for unlit tunnel driving
- “reverse driving” view camera
- state-of-the-art, electronically controlled diesel engines according to Tier 3 classification
- catalytic converter and exhaust particle filter
- fire-extinguishing system
the option of electric over hydraulic power for equipment working statically for longer durations (for example, explosives charging or lifting equipment at the tunnel face)
- robust and stable carrier
- hydraulic and electric components designed for use in harsh environments
- for utility function vehicles, modular carrier construction allowing multi-purpose utilization of the same carrier

3. Man Lifting Equipment

Man lifting applications are required in several phases of underground work such as explosives charging, manual scaling, installation of ground reinforcement and support, as well as in all kinds of utility works typically carried out behind the tunnel face. Functions like geological mapping and the monitoring of ground control systems need work platform service as well.

Specific tunnel dimensions and work methods set the minimum requirements for the reach and lifting capacities of the equipment. Tunnel specific equipment provides more efficient and versatile solutions for underground works when compared to conventional lifting equipment like scissors lifts and telescopic handlers, and provides greater tramming efficiency versus simple boom lifters.

3.1 Tunnel specific boom and basket concepts vs. conventional lifting devices

Tunnel specific man lifting devices typically use one or two multi-directional operating booms with a total slew angle up to 60 degrees, providing a true three dimensional working zone (longitudinal, vertical and horizontal) in the tunnel. With a multi-directional operating boom and basket system, the operator can reach the full tunnel profile without the need to reposition the carrier in a horizontal direction. Conventional telescopic handlers usually provide the boom movements only in 2-directions (longitudinal and vertical) and scissors lifts usually come only with vertical and minimal lateral movement. Movements across the face with a conventional lifting device can be provided only by moving the carrier sidewise in the tunnel which brings unnecessary delays to the work process.

Tunnel specific booms are structured to be more robust and are typically welded from heavier steel than conventional booms. Lifters are designed to stay stable and maintain operator safety even in extreme situations such as falling rock hitting the boom structure. Conventional light lifting devices often cannot remain stable in such situations and this is a noticeable safety issue to be evaluated when selecting lifting devices for tunnel works.

One advantageous feature of a tunnel specific lifting device is that it can be operated from the basket. This is a big benefit compared to conventional telescopic handlers that usually need an additional operator sitting down in the driver’s cabin or adjacent to the machine. To contrast, "telehandlers" are designed primarily for the rapid movement of palletized cargo or other loads on surface applications by using pallet forks and adapting them to man lifting works is often done with a non-ideal lift table attachment that replaces the forks.

Drilling jumbos may have an additional boom and basket which is designed for light man lifting works while the machine is stationary at the face. In this case, the basket may be used for the manual handling of rods when doing long hole drilling such as for grout holes or it can also be used for small scale scaling and or support works at the face in conjunction with the drilling procedure. However, because the drill jumbo often has multiple faces to operate and a high investment cost, it is not beneficial to use the drill jumbo for other lifting applications. All other works at tunnel face may be accomplished faster by using tunnel specific two boom lifters.
Figure 1. Installation of wire mesh and light steel supports from a twin boom Himec 9905 BT photo courtesy of Zublin, Germany

According to the new European Machinery Directive, which came into effect on Jan 1st 2010, a safety roof is compulsory in all man lifting devices in underground works if there is a risk for falling objects. Tunnel specific lifting devices come with a FOPS approved operator's safety roof as standard. A safety roof can be set back or removed totally when works are done under a supported roof such as in final tunnel lining structures.

3.2 Twin boom lifter concept

A twin boom concept such as the Himec 9905 BT (Fig. 1) with a 500 kg total lifting capacity per basket is a versatile solution for typical medium load lifting works at the tunnel face. The reach from one set-up to 11.7m height and to 16 m total lateral width covers most tunnel profiles used in civil construction today. Two booms allow works to be carried out by two independent operators at the face. This can cut down cycle time remarkably compared to single boom operation from the basket of a drill rig or a conventional telescopic handler. Time savings in the installation of light steel arches, wire mesh, anchors and drainage systems vary between 20-40 %. In face charging works, time economies of up to 50 % can be attained compared to one man operation from one basket.

3.3 High reach boom and large basket lifter concept

A high reach boom concept such as the Himec 9915 B or Charmec 9910 B REX (Fig.3) uses a heavy duty boom and work platform capable of lifting loads of 1500 kg and 1000 kg respectively. The large basket can easily lift up a multiple worker crew with necessary tools and materials. A maximum 9.0 m platform height allows a working reach up to 11 m. The working area of the basic 9915 B platform is 2.4 x 2.4 m but the hydraulically extendable REX-platform provides a variable horizontal plane up to 2.40 x 4.70 m.

The 2.4m boom extension enables maintenance of the platform a safe distance from the tunnel face during its entire vertical travel. Platform rotation permits lining up parallel to the face when slewing the boom through a 60° slewing range. The large working area of the platform allows simultaneous work by several operators, thus making the product favorable for the explosives charging of large tunnel faces by a charging team. High lifting load and large coverage have made it a popular configuration also for utility works like ventilation ducting, electrical works and piping for water and compressed air conveyance. The stable construction also permits use for sampling, measuring, surveying, roof bolting and manual sprayed concrete applications.
Figure 2. Overall ranges of multi-directional operating boom and basket concepts utilised in tunnel specific lifting and charging equipment

Figure 3a & b. Charmec 9910 BC REX unit comes with Normet Superboom and the largest tunnel specific working platform available in the market. The platform has hydraulically operated side extensions and 340 degrees rotation. *photo courtesy of Geotunnel, Spain*
4. Explosives Charging Concept for Large Tunnels

Recent years have seen a clear trend in explosives consumption from Anfo and cartridge explosives to site sensitized bulk emulsion explosives in tunneling. As an example, during the last five years, approximately 75% of all underground projects in Scandinavia have been accomplished by utilising site sensitized emulsions.

Bulk emulsions have several benefits when compared to Anfo and cartridges in tunnelling works:

- higher overall safety as site-sensitised emulsions are classified as explosives only after adding a gassing agent into the bulk matrix during the pumping of the material into the blast hole
- easier and more efficient worksite logistics and storage procedures with the handling and transporting of the bulk matrix (Class 5.1) and not explosives (Class 1.1)
- bulk material has a significantly less expensive unit price per kg than cartridge explosives
- the critical diameter of today’s high quality underground emulsion explosives enables the efficient adjustment of the hole charge down to 17 mm in perimeter holes (for controlled profile blasting) allowing the use of bulk emulsions in all face holes
- water in oil (W/O) emulsions are not moisture sensitive like Anfo which means that charging works can be simplified and efficient even in wet ground conditions

From an equipment point of view, bulk emulsion explosives have also the following interesting features:

- bulk material can be pumped into the hole it allowing higher mechanization and automation levels compared to the manual loading of cartridge explosives
- higher mechanisation and automation levels make it possible for a contractor to use purpose built charging equipment that speed up the charging works considerably
- a higher automation level allows full registration of the round’s explosives information down to the level of hole specific data

As an example, the Charmec 2000 BEA concept (Figs. 4&5) is a tunnel specific charging vehicle especially designed for large tunnel profiles like automotive traffic tunnels. The 2 x 1000 litres Anfo vessels and 1 x 2000 kg emulsion matrix tank provide enough explosives for at least two large tunnel rounds before refilling of the tanks is needed. The two booms and baskets are equipped both with bulk emulsion and Anfo loading hoses. This makes it possible to use both charging methods simultaneously in the same round.

Figure 4. Tunnel specific charging equipment Charmec 2000 BEA for large tunnel profiles and bulk explosives, Anfo and bulk emulsion. *Photo courtesy of Lemminkäinen, Sweden*

In large tunnels, the explosive material cost per linear meter can be minimized by using bulk emulsion in profile holes as well as in the next row holes instead of much more expensive packaged explosives (cartridges or pipe charges). Anfo can be used in other blast and cut holes where conditions allow. In a typical railway tunnel, case studies show that the explosive material cost can be cut by 15-20% if packaged products in profile holes can be replaced fully by bulk emulsion. Time savings of up to 50% can simultaneously be attained in the face charging process as profile holes can be charged by mechanised hose reel and manual charging is...
eliminated. In wet ground conditions, all the face holes can be loaded with emulsion. Finnish contractor Lemminkäinen has been a pioneer, using this method with success in several road (E18 motorway) and railway tunnel projects (Botniabana and Ådalsbana) in Finland and Sweden since 2005.

Figure 5. Tunnel specific twin boom Charmec 2000 BEA with the maximum working reach from one set up to 11.7 m high and to 16 m total width, specially designed to speed up blasting works in traffic tunnels. *Photo courtesy of Lemminkäinen, Finland*

5. Steel Arch Installation Equipment

Heavy steel arch installation is an inseparable part of many conventional tunnelling operations in softer ground conditions. Steel arches are typically curved I-profiles made from variable thickness steel. In smaller tunnels, the steel support may be formed by using only one steel arch which is curved in relation to the tunnel profile. In larger tunnels, steel arch support is formed by building the final arch over the profile from 2-5 separate curved I-profiles. The weight of a steel arch piece to be lifted varies typically from 250 – 1000 kg.

Figure 6. Tunnel specific arch lifting equipment Himec 9915 BA with max steel arch lifting capacity of 1350 kg in and max lifting reach 11.1 m *Photo courtesy of Vinci, France*

Because of extremely heavy loads, no compromise with work safety during the lifting work may be tolerated. Only purpose-built arch lifting and installation equipment (Fig. 6) should be used for heavy steel support works as any other construction machine cannot provide a satisfactory working environment for the operator and nearby personnel. Installation works carried out from a wheel loader bucket or the lifting of steel arches by using a telehandler’s fork lift are not acceptable work methods.
Figure 7 a-h. Photo series showing robotic arch lifting equipment Himec 2000 BAQ with two ejector booms and two man lifting booms at work in the railway tunnel Lot 6 for Sochi 2014 Winter Olympics Park. *photo courtesy of Bamtonnelstroy, Russia*
Tunnel specific arch lifting equipment comes with a robust and stable tunnel carrier, a telescopic manipulator (ejector) system for mechanised lifting and installation of the steel support, and a basket concept that provides a safe working place for the operators.

As an example, Normet’s Himec 9915 BA uses precision hydraulics on the robotic arm which can handle a steel arch with maximum load of 1350 kg. The arm can lift the arch, position it precisely and maintain its position fixed. The final fastening of the steel arch to anchors and/or adjoining steel support can then be carried out safely from the basket by the operator(s). The 1615 kg platform lifting capacity and rotation of 340 degrees makes this archlifter multi-purpose and useful for most man lifting and installation tunnel works. A “screen kit” for wire mesh installation is one of the most common options.

As another example, the Himec 2000 BAQ (Fig.7) is well suited for the robotic erection of heavy steel supports in large profile tunnels up to 11 m height and 18 m wide. It has twin erector booms with extensions of 4000 mm and comes equipped with hydraulically controlled grapples and twin boom and basket systems for man lifting. The maximum lifting capacity of the erectors is 2 x 1000 kg. Man lifting capacity is 2 x 500 kg. The arch installation work cycle in the railway tunnel for the Sochi 2014 Winter Olympic Games details the pick up of the steel arches from the storage facility (Fig.7a) and carriage to the face (Fig. 7b). During the transportation the boom carriage is in its rearmost position and the erector booms are folded to the side of the carrier (Fig.7c). At the face, the boom carriage is pushed to the foremost position (Fig.7d) and the ejector booms holding the steel supports are extended (Fig. 7e). Both ejector booms can be operated simultaneously and they allow a precise positioning of the steel support to the tunnel profile (Figs. 7f & 7g). Steel arch positions are maintained by the ejectors until the final fastening of the arch is completed from the two man lifting baskets (Fig. 7h).

The unique robotic concept cuts the cycle time of steel arch installation (two operators) by up to 40-50 % compared to single ejector boom units. The safety provided compared to the use of conventional, modified equipment is dramatic and permits halving the crew size at the face.

6. Conclusion

Tunnel contractors are innovative, “get it done”, industrious people and have demonstrated a remarkable ability to adapt equipment and work methods to their needs over the years. As the pace of development of underground infrastructure increases, however, these same contractors are turning to tunnel specific equipment to meet their needs safely, efficiently and economically. While it is conceivable that adaptations of mining specific and other equipment will still be used in tunneling, especially where the profile is relatively small, there is a trend to growing demand from suppliers for equipment that is suited to mechanization, labor saving and, in some cases, automation of tunnel development processes.

This paper has dealt with, in particular, tunneling processes whereby workers/operators are exposed in close quarters to the working face and unsupported backs. Here, the benefits of purpose-built vehicles are relatively obvious yet, over the last five years, significant improvements to the equipment have yielded benefits for the operating contractors.

It is the intent of the authors to address the areas of concrete spraying, scaling and transportation in a subsequent paper.