

HIGH-EFFICIENCY INSTALLATION OF PIPE UMBRELLA

Umbrella installation in a fraction of the time with reduced risk of collapse

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SAMMENDRAG

Når det påtreffes ekstremt dårlig berg foran stuff, vil det oftest bli overveid å benytte for-forsterkning med innboring av rørskjerm. De fleste eksisterende systemer krever i så fall spesialutstyr eller omfattende tilpasninger for en standard borrhigg. Det kan ta flere uker for nødvendige forberedelser, spesielt hvis slike forhold kommer uventet. Lav kapasitet ved installasjon av rørskjermer gjør også at en beslutning kan bli vanskelig å ta. Erfaring gjort av finsk entreprenør YIT Sverige AB i Stockholm viser at å utføre en 15 m lang rørskjerm med 35 rør vil typisk ta tre døgn. Usikkerhet om *hvor* vanskelige forholdene vil bli, kan stoppe eller utsette en beslutning, noe som kan gi vesentlig økt risiko for stabilitetsproblemer eller kollaps. Hvis forholdene i stedet blir bedre enn ventet, vil tidkrevende bruk av rørskjerm føre til ekstra tidstap.

YIT har tatt i bruk en ny metode for innsetting av rørskjerm i Stockholm. Ved å utnytte et standard stangmagasin for langhullsborring, kan 15 m lange rør installeres uten bruk av manuell medvirkning. De 35 rør nevnt foran blir med denne løsningen innsatt på 12-15 timer og nødvendige tilpasninger på boreriggen kan utføres på ett skift.

Ved ekstremt dårlig berg foran stuff, er den største risikoen for kollaps sterkt knyttet til vannforholdene og åpningen (avstanden) mellom naborør i skjermen. Den nye metoden inkluderer en løsning for trykkinjeksjon av berget umiddelbart rundt rørene. Når det er nødvendig, kan trykkinjeksjon brukes til å blokkere strømmende vann og øke skjærmotstanden til slepper og sprekker. Dette er spesielt viktig i området *mellom* installerte rør. Åpen stabil tid ved senere sekvensiell fremdrift under rørskjermen, vil bli vesentlig forbedret. Dette vil gi mer tid til påføring av sprøytebetong og bruk av andre sikringsmidler før nedfall oppstår.

Den nye metoden gir bedre stabilitetskontroll utført vesentlig raskere, samtidig som HMS-forhold for mannskapet er forbedret. Når det også tas hensyn til reduksjon av tid for forberedelser, kan samlet reduksjon av kostnader bli stor.

SUMMARY

For sections of poor ground conditions in hard rock tunneling, using pre-support by pipe umbrellas may be the solution. Most existing systems need special equipment or elaborate adaptations to standard drill jumbos, which may require

weeks of preparation time. This may cause significant delays when unexpectedly hitting poor ground. In any case, the low installation output makes it a tough decision to initiate pipe umbrella installation. Experience gained by Finnish contractor YIT Sverige AB in Stockholm shows that a 15 m long umbrella consisting of 35 spiles may typically take 72 hours. Uncertainty about *how* difficult the conditions will be may stop an umbrella decision, increasing the risk of serious stability problems. In contrast, umbrella installation into better-than-expected ground will, in hindsight, cause unnecessary time loss.

YIT introduced a new method of pipe umbrella installation that significantly alleviated these obstacles. Using the rod-handling magazine available for long-hole drilling on standard drill jumbos, YIT installed 15-meter umbrella spiles without manual interaction. The 35 spiles mentioned above took 12-15 hours, and the initial adaptations necessary on the drill jumbo took about one shift.

The main risk of collapse occurs when excavating into extremely poor ground, typically linked to groundwater and the openings *between* the umbrella spiles. The new method offers solutions for pressure grouting of the rock mass surrounding the installed spiles. When necessary, pressure grouting can block groundwater flow and increase the shear resistance of cracks and joints, especially critical in the space between spiles. Significantly improved open stable stand-up time when later excavating under the umbrella will allow the application of sprayed concrete and other additional support during part-face excavation.

The new method offers improved stability control, umbrella installation completed in a shorter time, better EHS conditions for the operators, and significantly lower overall tunneling costs.

INTRODUCTION

The general impression of Scandinavian tunneling conditions is that they offer good-quality hard rock with minor stability problems, allowing high excavation rates. It is still normal that more than 5% of the tunnel length will pass through highly broken and extremely poor ground, such as that found in shear zones.

The cost of a D&B tunnel is sensitive to construction time, and even a limited percentage of the tunnel length crossing extremely poor ground may have a significant impact. The uncertainty about the length of the tunnel passing such ground and the degree of stability problems make it hard to estimate consequential time and cost. This applies to problem zones identified by geological pre-investigations, especially when unexpectedly hitting such conditions.

Installing pipe umbrellas to pre-stabilize and strengthen the ground ahead of the face is a well-known solution for tunneling through residual soil, complicated tunnel portal areas, and poor ground sections anywhere along a tunnel. Several solutions for pipe umbrella installation are available, with many different combinations of drilling principles, pipe diameters, pipe length, and placement equipment layout. Traditionally, all these solutions represent good alternatives for passing through known problem sections, even when requiring long preparation and installation time.

The reason is that the cost of face area collapse will easily be higher. See Figure 1.



Figure 1: Pipe umbrella illustration

Even though permanent rock support design usually does not include an installed pipe umbrella, the dimensioning of umbrella spiles is often still evaluated similarly. When excavating below the installed umbrella, the critical time will be during part-face sequential face advance before finishing the placement of sprayed concrete and other immediate temporary support measures. The open stand-up time of the ground *between* pipes must allow the installation of such immediate measures, enabling the later construction of permanent support.

YIT SVERIGE AB USING PD55 IN STOCKHOLM

The Finnish contractor YIT Sverige AB gained practical experience with the PD55 pipe umbrella system at the SFAL project (meaning Stockholm's future sewage cleaning). The tunnel cross-section that required pipe umbrellas is 100 m², and umbrellas were installed from both directions crossing the disturbance zone. YIT used the standard rod-handling system for long-hole drilling on their D&B drill rig. Such rod magazines allow placing up to 18 m long spiles without manual intervention. Up to six pieces of 3-m-long drill pipes can be pre-loaded in the magazine mounted on the feeder before positioning the boom to start a new spile, providing efficient insertion of subsequent drill pipes. See Figure 2.



Figure 2: Rod magazine Atlas Copco Sandvik with PD55 drill pipes loaded

Traditional pipe umbrella solutions use pipe diameters of 100 mm and more, which standard drill rod magazines cannot handle. Consequently, taking advantage of mechanized rod handling is not possible. The larger pipe diameters also require drilling with larger drill bits, reducing the penetration rate.

The PD55 system uses the umbrella pipe as a drill rod, fronted by a disposable drill bit of Ø66 mm. There is no need to spend time extracting drill rods after finishing the hole. Loading the rod magazine for the next spile is safely done at the invert level. The PD55 pipe wall thickness of 14 mm provides a large steel cross-section area, ensuring good energy transfer from the bore hammer to the drill bit, giving a high penetration rate.

YIT Sverige AB found that 35 pieces of 15-m-long spiles using traditional large-diameter pipes typically took 72 hours to install. YIT installed the same umbrella layout using PD55 in 12 to 15 hours. The PD55 experience data is based on 6300 m of installed spiles. The Q-classification of the rock mass where a pipe umbrella was installed was generally in the $0.1 < Q < 0.4$ range. The rock mass contained clay and graphite locally, causing Q-values < 0.1 (extremely poor ground).

Note that some pipe umbrella systems require a heavy, specialized, and expensive equipment unit, which may take weeks to mobilize for this purpose only. Other existing systems using the tunneling drill rig require quite elaborate modifications to the drill rig before the start of pipe umbrella installation. Construction sites with a drill rig and a rod handling magazine can make the necessary adjustments for PD55 installation in less than a shift, reducing the time spent preparing.

Technical details of PD55 umbrella pipes

Find the primary technical data for the PD55 umbrella pipes in Table 1:

Table 1: PD55 umbrella pipe, technical data

OD of pipe (mm)	ID of pipe (mm)	Pipe length (mm)	Thread type	Steel cross section (mm ²)	Elongation A5 (%)	Yield ReH (N/mm ²)	Failure Rm (N/mm ²)	Weight kg/pipe
55	27	3135	T45	1800	>17	>460	>540	44

PD55 pipes are manufactured using steel quality S460NH, and production is executed according to EN 10210-1:2006 to ensure the specified technical data are achieved.

The threads used are T45 links.

The accessories are Ø66 mm disposable drill bits T45 and the adaptor for the grout hose hookup, which allows injecting grout to embed the placed PD55 spile.

Preparing the drill rig

Long-hole drilling is routinely executed at many tunneling projects for probing ahead and pre-excavation grouting. A drill rod magazine will then substantially increase production capacity and improve working conditions and safety for the operators.

For the Atlas Copco Sandvik equipment used in Stockholm, YIT made the necessary adjustments to the rod magazine and drill in less than a shift. The changes consisted of the following:

- Change the neck adaptor of the bore hammer to one for PD55/T45
- Change the two rubber bushings supporting the drill-pipe feed during drilling
- Change to the 'star plates' intended for the PD55 pipes
- Check and adjust that the pipes are loaded and centered on the feeder
- Adjust all parameters of the hydraulic system for PD55 drilling

Placement of umbrella spiles

Accurate placement with minimal deviation gives the umbrella the best support effect. Therefore, it is essential to ensure straight-hole drilling.

Any good drill rig operator knows how to do this by accurately hitting the starting point, carefully and slowly advancing the drill into the rock, and, during drilling, making sure the drill pipe rotates freely and is centered in the borehole. The most important steps are to avoid having the drill bit slide on inclined surfaces during collaring and to use limited feeder pressure for the first pipe length.

Before starting a new splice, two operators reload the rod magazine (usually 5 or 6 pipes) with the feeder at the invert positioned alongside the stack of PD55 pipes. One operator at each end of the pipe stack will quickly load the 44 kg pipes. It is possible to load the magazine using only one person, with an optional pipe-handling hoist solution.

The umbrella layout is a matter of local design considerations to determine the look-out angle, length of spiles, and the spacing of collaring points at the face. The drilling will benefit from using a modern drill rig with a digital representation of tunnel data and umbrella design details. Normal splice spacing is 300-500 mm, but down to 200 mm is possible if required, demanding highly accurate drilling with minor deviation. Varying the umbrella overlap is a way of achieving increased support capacity, which is a realistic option due to the high production output of PD55 installation.

Grouting of the inserted spiles

Pumping grout through the pipe must allow it to pass through the drill bit, which should not rest against the bottom of the hole. Pull back the splice with the drill bit by 10 mm to provide the necessary opening for the grout to flow back through the annulus between the splice and the rock.

Use a high-quality, creamy, non-bleeding grout to embed and anchor spiles properly. If pressure grouting of the surrounding rock mass is desired, a grout of similar consistency based on microfine cement will improve penetration.

For wet conditions and pressure grouting into the surrounding rock, two solutions are available:

1. A plastic ring accessory is inserted around the outside of the pile to block the annular space. An adaptor on the bore hammer pushes the ring onto the pile end to slide 1-2 m into the borehole. Note that this solution requires the pile to be well-centered in the borehole, allowing the plastic ring to enter the borehole without problems. YIT points out that an improved solution should be developed.
2. Drill the planned pile length an extra 1-2 m forward, leaving the first 1-2 m of borehole free to insert an ordinary grouting packer. With the pile in place, the borehole forward of the packer gets pressure grouted. With this approach, the new piles do not extend backward through the face, which may require special support arrangements.

PD55 VERSUS CURRENT UMBRELLA SYSTEMS

General comments

Using pipe umbrellas to pre-reinforce the ground becomes an option when the excavation may encounter worse-than 'very poor' ground conditions (using the Q-system classification, $Q < 0.4$) ahead of the face.

Under such conditions, the *critical* problem is the short stable stand-up time when advancing the tunnel face, which may prevent placing immediate support before the start of fallout. Consequently, disregard considerations used to design permanent support at this stage since the umbrella's most crucial purpose is to prevent the rapid development of face collapse. When the umbrella allows unimpeded face advance and safe installation of immediate support, aspects of permanent support are no longer an urgent matter.

An installed umbrella will usually be at least 15 m long with a spacing of spiles at 300 to 500 mm. Excavation is done in short steps underneath the umbrella (1-2 m) while only a partial face area is opened. This way, sufficient stable stand-up time will allow the placement of fiber-reinforced sprayed concrete and other immediate support measures. Therefore, the load development onto umbrella spiles spanning partial-face openings is quite different and incomparable to the permanent support situation of a completed tunnel cross-section.

Experience shows that groundwater significantly influences the critical parameter of stable stand-up time (the time it takes before the start of sloughing and fallout from an unsupported tunnel contour). Especially when the groundwater head is high, silty, and similar fine-grained ground may quickly develop hydraulic collapse (flowing or running ground), or highly conductive channels may cause

concentrated water jets that can erode and flush material into the tunnel. One or both effects may cause a complete face area collapse, starting *between* the spiles. Unfortunately, there are limited options to stop such a collapse after the process begins.

New features of PD55

It is common sense to carefully evaluate the properties of a new way to execute any rock support method. However, consider the relevance of first impressions against the primary purpose of such support, as discussed above under the general comments.

The typical first observation is that spiles of Ø55 mm will have a smaller area of direct ground contact than spiles of more than double the diameter (since the projected area of spiles as a percentage of the total umbrella area is smaller). This is correct but of minor importance. In the typical case of a center distance of 500 mm between traditional spiles, the PD55 pile spacing would only need to be 10% smaller to compensate. However, the decisive factor regarding stability is what happens *between* the spiles when excavating. If the project recognizes this, the PD55 alternative offers two crucial benefits:

1. The option to execute pressure grouting into the surrounding rock mass. This will strengthen and stabilize the rock volume between spiles and block off water to reduce the water pressure gradient and risk of flowing ground and prevent water jet erosion from channels.
2. The excellent installation output allows reduced spacing of spiles without an increase in time or overall cost.

All umbrella systems use mortar injections to anchor the spiles to the surrounding ground. Grout enters through the end of the pipe and returns along the outside to appear at the collaring point. Large-diameter pipes may have perforations distributed along their length. The full pile length is treated one section at a time by pressurizing pipe sections between double packers. The anchoring of the spiles is equally good for these grouting approaches, but the double-packer approach will require more time.

However, the ability to grout the rock volume *between* spiles at additional pressure is crucial. The standard large-diameter pile systems do not include any practical solution in this respect. Without an effective blockage of the annular space near the collaring point, the grout will take the path of least resistance and run back to the tunnel at too low pressure for penetration into the rock mass.

The PD55 pipes' bending moment resistance is lower because of their smaller diameter. This observation is correct, but due to the 14 mm wall thickness of PD55 pipes, the steel cross-section area is still about the same as larger-diameter pipes. Furthermore, higher steel quality, fixed endpoints due to mortar embedment, and limited length free span (short excavation steps) reduce the importance of bending moment considerations. After stepwise part-face excavation has exposed fresh tunnel contour underneath the umbrella, the composite action with the ground will maintain the existing short-term stability without attracting a high load.

Immediate additional temporary support will slow down radial convergence, and the bending moment is unlikely to become a dimensioning load case.

CONCLUSIONS

The PD55 system offers a new alternative for the installation of pipe umbrellas. The primary advantages of the system are:

- Significantly reduced time for umbrella installation when utilizing standard drill rig rod handling magazines for long-hole drilling.
- Two ways to pressure-grout the rock mass around the umbrella spiles can improve the ground *between* spiles and prevent groundwater from creating flowing ground or rapid erosion by concentrated water jets.

The primary purpose of pipe umbrellas is to achieve immediate temporary support by avoiding (as far as possible) the risk of collapse. Compared with commonly used larger diameter pipe systems, the most frequent reservations to PD55 are based on permanent support structural considerations that are limited in relevance to the often *critical* first 60-120 minutes after exposure created by the part-face excavation steps.

Because of the excellent time and cost factors, reduced spile spacing, increased umbrella overlap, and pressure grouting of the surrounding rock mass can be adopted without prohibitive cost increases. These are all realistic steps to overcome problematic ground conditions.

As a bonus, operators unanimously agree that PD55 significantly reduces the physical workload and improves work safety. Site Manager W. Klasér prefers the PD55 alternative whenever the choice is approved.

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