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High-efficiency installation of pipe umbrella

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ABSTRACT: Hard rock tunneling sometimes requires the use of pipe umbrellas for pre-support, particularly in areas with exceptionally poor ground conditions. Most existing systems necessitate specialized equipment or extensive modifications to standard drill jumbos, which can take weeks to prepare. This preparation time can lead to significant delays, especially when encountering unexpected poor ground. Additionally, the low installation output complicates the decision-making process regarding whether to install pipe umbrellas. The new PD55 umbrella system addresses these decision-making challenges by allowing for the adaptation of the drill jumbo in a single shift and enabling the umbrella installation to be completed in 20% to 50% of the usual time.

1 INTRODUCTION

Overall, Scandinavian tunneling conditions are characterized by good-quality hard rock with minor stability issues, enabling high excavation speeds. It remains common for more than 5% of the tunnel length to pass through highly broken and extremely poor ground, such as that found in shear zones.

The cost of a tunnel is susceptible to construction time, and even a small percentage of the tunnel crossing very poor ground can have a significant impact. The uncertainty about how much of the tunnel will pass through such ground and the unknown seriousness of stability problems make it difficult to estimate the associated time and cost.

Installing pipe umbrellas to pre-stabilize and strengthen the ground ahead of the face is a well-known solution for tunneling through residual soil, complex tunnel portal areas, and poor ground conditions along the tunnel. Several methods for pipe umbrella installation are available, offering various combinations of drilling principles, pipe diameters, pipe lengths, and placement equipment. Traditionally, these solutions are effective options for passing through problem sections, as they help avoid the high costs associated with face area collapse. See Figure 1.

Figure 1. Pipe umbrella illustration, principle.

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Although permanent rock support design typically does not consider an installed pipe umbrella, it is often evaluated in a similar manner. When excavating beneath the installed umbrella, the critical period occurs during the part-face sequential advance, before the benefit of sprayed concrete and other immediate support measures are in place. The open stand-up time of the ground between pipes must allow for the installation of these immediate measures, facilitating the subsequent construction of permanent support.

2 YIT SVERIGE AB USING PD55 IN STOCKHOLM

The Finnish contractor YIT Sverige AB gained practical experience with the new PD55 pipe umbrella system during the SFAL project (an acronym for Stockholm's future sewage cleaning system). The tunnel cross-section requiring pipe umbrellas measures 100 m2, and umbrellas were installed from both drive directions crossing the disturbance zone. YIT used the standard rod-handling system for long-hole drilling on its drill-and-blast rig. This rod magazine allows the placement of up to 21 m-long spiles without manual intervention. YIT pre-loaded five 3-m-long drill pipes into the magazine mounted on the feeder before positioning the boom to start a new spile, enabling efficient insertion of subsequent drill pipes for a total length of 15 m. 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 or more, which standard drill-rod magazines cannot accommodate. As a result, fully mechanized rod handling is not feasible. Larger pipe diameters also require larger drill bits, which reduce penetration rate.

The PD55 system uses the umbrella pipe as a drill rod, topped with a disposable drill bit of Ø66 mm. There's no need to spend time removing drill rods after completing 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-sectional area, ensuring efficient energy transfer from the bore hammer to the drill bit and helping achieve a high penetration rate.

YIT Sverige AB found that installing 35 15-meter-long spiles using traditional large-diameter pipes typically required 72 hours. In contrast, YIT installed the same umbrella layout with PD55 in 12-15 hours. The YIT PD55 experience data is based on the installation of 6,300 meters of spiles. The rock mass where the pipe umbrella was installed was generally classified as Q between 0.1 and 0.4. Locally, the rock contained clay and graphite, leading to Q-values below 0.1, indicating 'extremely poor' ground. NGI (2015). Later, Skanska Norge AS achieved similar results, installing 1,200 m of PD55 spiles in the Gullberg tunnel (E10 highway South of Tromsø, Norway).

Note that some pipe umbrella systems require heavy, custom-made, and expensive equipment, which may take weeks to arrange solely for this purpose. Existing systems that use the tunneling drill rig require significant modifications to the rig before commencing pipe umbrella installation. Construction sites with a drill rig equipped with a rod-handling magazine can make the necessary adjustments for PD55 installation within a single shift, thereby avoiding waiting time.

3 PARTICULARS OF USING PD55 UMBRELLA PIPES

3.1 *Technical details of the drill pipes*

PD55 pipes are manufactured from steel grade S460NH and produced in accordance with EN 10210-1:2006 to ensure compliance with the specified technical data. Møller (2024). The threads used are T45 links.

The accessories include Ø66 mm T45 disposable drill bits and an adaptor for the grout hose connection, which allows grout to be injected to embed the placed PD55 spile in the borehole.

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 stress (N/mm^2)	Failure stress (N/mm^2)	Weight kg/pipe
55	27	3135	T45	1800	>17	>4660	>540	44

3.2 *Preparation of the drill rig*

Long-hole drilling is commonly used in tunneling projects to probe ahead and perform pre-excavation grouting. A drill rod magazine significantly increases production capacity while enhancing working conditions and operator safety.

For the Atlas Copco Sandvik equipment used in Stockholm, YIT made the necessary adjustments to the rod magazine and drill within a single 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

3.3 *Placement of umbrella spiles*

Precise placement with minimal deviation provides the umbrella with optimal support. Therefore, ensuring straight-hole drilling is essential.

A skilled drill rig operator accurately collars the borehole, carefully and slowly advances the drill into the rock, and ensures that the drill pipe rotates freely and remains well centered in the borehole. The most important steps are to prevent the drill bit from sliding on inclined surfaces during collaring and to apply limited feeder pressure for the first pipe length.

Before starting a new spile, 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. The magazine can be loaded by a single person using an optional pipe-handling hoist.

Local design considerations, including the lookout angle, spile length, and spacing of the face collaring points, determine the umbrella layout. Using a modern drill rig equipped with a digital geo-positioning system and a preloaded umbrella design will improve drilling accuracy. Typical spile spacing is 300-500 mm, but it can be reduced to 200 mm if needed, requiring precise drilling with minimal deviation. If necessary, the support capacity can be further increased by overlapping umbrella layers. Owing to the high production output of the PD55 installation, this approach is not becoming prohibitively expensive.

3.4 *Grouting of the inserted spiles*

Grout placement is helped by ensuring that the drill bit does not rest against the bottom of the hole. Pull back the spile and drill bit by 10 mm to create a good opening for grout to flow back along the annulus between the spile and the rock. A moderate grout pressure of 5 bar will be adequate.

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

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

1. A plastic ring 'packer' accessory is placed onto the outer end of the spile to block the annular space by pushing the ring 1-2 m into the borehole. This can be done manually using a pipe adaptor and a hammer. Note that this method requires the spile to be well centered in the borehole so that the plastic ring can be inserted without difficulty.
2. Drill the planned spile length an extra 1-2 m forward, leaving the first 1-2 m of the borehole free to insert an ordinary grouting packer. With the spile in place, the borehole ahead of the packer is pressure-grouted. With this approach, the new spiles do not extend backward through the face, which may require special support arrangements.

For pressure grouting by cement into the surrounding rock, the grout pump should be rated at 50 bar or more, Using colloidal silica works well at lower pump pressures.

4 PD55 VERSUS CURRENT UMBRELLA SYSTEMS

4.1 *General comments*

Using pipe umbrellas to pre-reinforce the ground becomes an option when excavation might encounter worse-than-'very poor' ground conditions (using the Q-system classification, $Q < 0.4$) ahead of the face. NGI (2015).

Under such conditions, the main issue may be a short, stable stand-up time as the tunnel face advances, potentially hindering the placement of immediate support before fallout begins. Therefore, ignore considerations used in the design of permanent support at this stage, as the primary purpose of the umbrella is to provide safe conditions for placement of immediate support. When the umbrella allows the face to advance, and the installation of immediate support, permanent support design becomes a routine task.

An installed umbrella will typically be at least 15 meters long, with spiles spaced 300-500 mm apart. Excavation is carried out in short steps beneath the umbrella (1-2 meters), opening only a partial face area at a time. This approach ensures sufficient, stable stand-up time to allow placement of fiber-reinforced sprayed concrete and other immediate and permanent support measures. Therefore, the time-dependent load development on umbrella spiles spanning partial-face openings differs substantially and cannot be directly compared with the permanent support requirements for a completed tunnel cross-section.

Experience shows that groundwater significantly affects the critical parameter of stable standup time—the duration before sloughing and fallout begin at an unsupported tunnel contour. Especially when the groundwater head is high, silty and similar fine-grained ground can quickly develop hydraulic failure (flowing or running ground), or highly conductive channels may create concentrated water jets that erode and flush fine material into the tunnel. One or both of these effects can lead to complete collapse of the face area, beginning between the spiles. The highest risk of losing stability control is directly linked to presence of groundwater, and the best mitigation is pressure grouting of the rock mass surrounding the spiles. Unfortunately, options for stopping such a collapse once it has started are typically not available.

4.2 *New features of PD55*

It is common sense to carefully evaluate the properties of any new method for installing a rock support system. However, the first impressions should reflect the primary purpose of such support, as discussed above under the general comments.

The initial common observation is that Ø55 mm spiles have a smaller ground-contact area than spiles with diameters more than twice that size, because their projected area is smaller relative to the total umbrella area. This is a correct observation, but of minor importance. In the typical case of a 500 mm center-to-center spacing between traditional spiles, the PD55 spile spacing would need to be approximately 10% smaller to compensate for this difference. Nonetheless, the key factor for stability is what may happen in the short term between the spiles when moving the face forward. If a project considers this, the PD55 alternative offers two critical advantages.

1. The option to perform pressure grouting into the surrounding rock mass. This will strengthen and stabilize the rock between spiles, block water flow to reduce the water pressure gradient, and reduce the risk of flowing ground and water-jet erosion from any open channels.
2. The excellent installation output enables close spacing (or umbrella overlap) of spiles with acceptable increase in time and cost.

All umbrella systems utilize mortar injections to anchor the spiles to the surrounding ground. Grout flows through the pipe end and returns along the exterior to the collaring point. Large-diameter pipes may have perforations spaced along their length. The full length of each spile can be treated in sections by pressurizing pipe segments between double packers. The anchoring effectiveness of the spiles is comparable across these grouting methods, but the double-packer method requires more time.

However, the ability to grout the rock volume between spiles at a higher grout pressure is essential. The standard large-diameter spile systems lack a practical solution for this option. Without effectively blocking the annular space near the collaring point, the grout will follow the path of least resistance and flow back to the tunnel at a pressure too low for proper penetration into the rock mass.

4.3 *PD55 load capacity*

The PD55 pipes have lower bending-moment capacity due to their smaller diameter. However, because they have a 14 mm wall thickness, the steel cross-sectional area remains roughly the same as that of larger-diameter pipes. Additionally, higher steel quality, fixed endpoints due to mortar embedment, and a limited support span (short excavation steps) reduce the significance of bending-moment considerations during the critical time window for immediate sprayed-concrete support. After step-by-step partial-face excavation exposes fresh tunnel contours beneath the umbrella, the composite action with the ground will provide short-term stability without imposing excessive bending loads. Adding support (sprayed concrete) immediately will slow radial convergence, and the bending moment is unlikely to become a critical load case.

The Norwegian Geotechnical Institute (NGI) has compared three umbrella pipe dimensions; further details are provided in Olsen & Skretting (2025). The findings are summarized in Table 2.

Table 2. PD55 umbrella pipe compared to Ø89 and Ø114 mm pipes.

Umbrella pipe diameter (mm)	PD55 Ø55	Ø89	Ø114
Pipe wall thickness (mm)	14	8	6.3
Dimensioning yield stress (MPa)	533	338	338
Umbrella pipe spacing c/c (m)	0.125	0.3	0.3
Loading stress (MPa)	457	446	308
Utilized load capacity of spile (%)	86	132	91

Note that the comparison is based on full compensation for the reduced bending-moment resistance of the PD55 pipes by installing 2.4 times as many spiles. Because of the high installation output, the finished PD55 umbrella would still be completed in approximately half the time. Again, the fully excavated cross-section load case can be avoided by properly sequencing work steps as the face advances, allowing the post-excavation immediate and permanent support of sprayed concrete and radial rock bolts to carry the load case of the fully excavated tunnel.

The detailed design considerations of the NGI (2025) reference cannot be included here due to space limit, but the unrestricted referenced document is available to the interested reader.

5 CONCLUSIONS

The PD55 system provides a new option for installing pipe umbrellas. The main benefits of the system are:

- Significantly reduces the time needed for umbrella installation by using a slightly modified standard drill rig rod handling magazine for long-hole drilling.
- Two methods to pressure-grout the rock mass around the umbrella spiles can improve the ground between spiles and prevent groundwater from causing flowing ground or rapid erosion caused by concentrated water jets.

The primary purpose of pipe umbrellas in hard rock tunnelling is to provide immediate temporary support by minimizing the risk of face area collapse in poor ground. Compared to larger-diameter pipe systems, the principal objections to PD55 stem from treating the umbrella as a permanent support structure. Given that the critical phase of tunnel advance can occur within the first 60-120 minutes after the initial partial-face advance, the permanent load case is inapplicable in this situation.

Given favorable time and cost factors, reduced spile spacing, increased umbrella overlap, and pressure grouting of the surrounding rock mass can be adopted as required, without prohibitive cost increases. These are available practical steps to address challenging ground conditions.

As a bonus, operators unanimously agree that PD55 significantly reduces physical workload and enhances work safety. Klasér (2024).

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