DSI UNDERGROUND

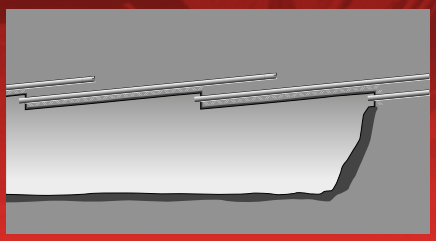
AT – Pipe Umbrella System

Groundbreaking Forepoling Technology

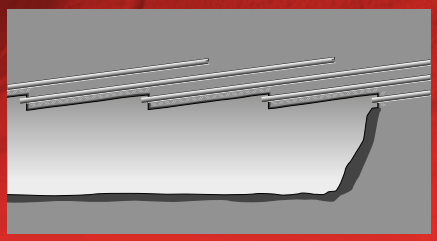
Fields of Application

- Advances in weak or heavily sheared ground
- Ground conditions prone to subsidence
- Advances in fault zones, sediments, or talus
- Frequently changing ground conditions
- Portal sections
- Re-excavation of collapsed drifts or tunnels
- Urban Tunneling

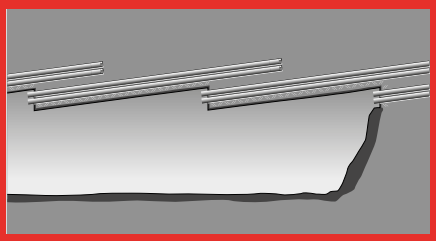
Single AT – Pipe Umbrella



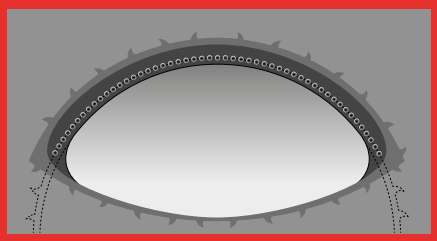
Single AT – Pipe Umbrella with Double Overlap



Double AT – Pipe Umbrella



Cross Section under an AT – Pipe Umbrella



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Introduction

The AT – Pipe Umbrella System is a pre-support measure used in weak ground conditions in conventional as well as mechanized Tunneling.

Long forepoling using the pipe umbrella or canopy method is typically applied to increase safety and stability in the working area of standard advance operations, portals, and for re-excavating collapsed sections.

Another application is ground improvement and waterproofing in combination with all tunnel construction methods.

Pipe umbrella pipes – installed into the ground prior to excavation – increase the stability in the working area by transferring loads in the longitudinal direction and decrease excavation induced deformations. DSI Underground has developed a superior pipe connection type which allows the reduction of installation cycle times while increasing the load-bearing capacity.

State-of-the art pipe umbrella support systems are installed self-drilling where the casing provides an immediate support of the borehole, compared tow outdated pre-drilling systems where borehole drilling and pipe installation takes place in two different working steps.

Fully mechanized installation is becoming a mandatory safety standard in the global Tunneling business.
DSI Underground is the leading system supplier in the development and application of safe and efficient pipe umbrella installation technology.

Main Advantages

- Supreme safety due to fully mechanized installation
- Efficient self-drilling installation technology
- The fastest pipe umbrella system on the market
- Installation with conventional drilling machines
- Implementation of pipe umbrella drilling with on-site personnel
- Reliable and robust system components
- Piecewise pipe installation allows flexible lengths
- Simple application in confined space
- Superior load-bearing capacity of innovative pipe couplings

System Components

Consumables

- Starter unit with drill bit
- Pipe umbrella pipes
- Injection valves

Multiple-Use Accessories

- Drill bit adapter
- Drill steel
- Grouting packer

Pipe Umbrella Design

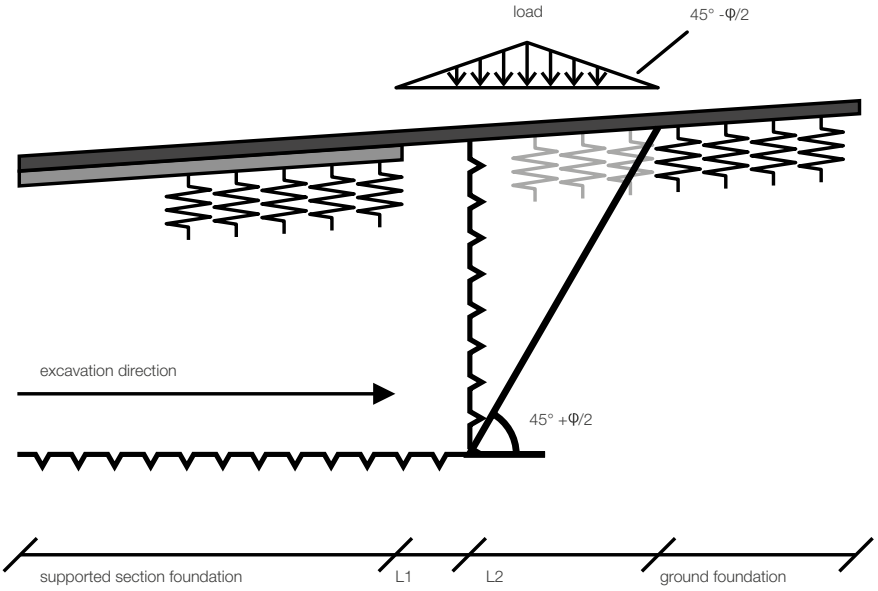
Support Effect

Pipe umbrella support systems with a typical installation length in the range of 12 [m] to 18 [m] are considered to be a long forepoling system. From a design perspective, supporting measures can be divided into three different effects:

- Subdivision of the unsupported zone in the open span of the working area
- Radial supporting effect
- Longitudinal supporting effect

Their interaction results in the support of the working area and face region. Loads in this critical section are transferred by each single umbrella pipe in the longitudinal direction to its foundations – the ground ahead of excavation and the already installed primary lining.

Pipe umbrella pipes are primarily loaded by bending. Therefore, the relevant design parameter is the maximum elastic moment of the system. The benchmark criterion is the performance of the weakest link, which usually is the pipe connection.



Volkmann & Schubert 2010

Design Criteria

There are two common design criteria for the load transfer of pipe umbrella pipes:

- Maximum elastic moment M_y of both the standard pipe and the pipe connection – pure elastic design.
- Elastic moment M_y of the standard pipe in combination with the ultimate moment Mult of the pipe connection – elastic-plastic design.

For both criteria, parameters relevant for design (M_y and M_{ult}) are productspecific and must be verified by adequate certificates from the manufacturer before installation.

In case plastic material reserves of steel are activated by plastic joints in the pipe connection area, a safety factor of at least 1.3 to the tested value M_{ult} is recommended:

- $M_{ult,\ pipe\ connection} \geq 1.3\ M_{y,\ standard\ pipe}$

This allows an elastic calculation and dimensioning of standard pipe umbrella pipes featuring state-of-the-art pipe connections without any further reduction of the load-bearing capacity.

Pipe Connection Types

Standard Threaded Connection

For a standard threaded connection, outside and inside threads are cut into both ends of each pipe umbrella pipe. This connection type reduces the cross-section of the pipe in the threaded area. This way, the section modulus is decreased as well. The internal pipe diameter in the connection area stays constant.

Besides the geometrical conditions of the thread, the overall quality of threaded pipes is a concern for the load-bearing capacity. In general, calibrated pipes reach a higher resistance against bending than non-calibrated ones.

Squeezed Connection

A squeezed connection consists of a prefabricated reduced male pipe end which is force-fitted with its female counter piece using a hydraulic clamping cylinder. In the coupling area, the cross section stays constant and the section modulus is decreased. The internal pipe diameter in the connection area is reduced.

This pipe connection type can be recommended where a pipe umbrella is installed because of its static load-bearing capacity.

Squeezing Unit

- Application in combination with default drilling machines
- Easy to handle and remote-controlled
- Safe and rapid pipe connection
- Hydraulically driven

Nipple Coupling

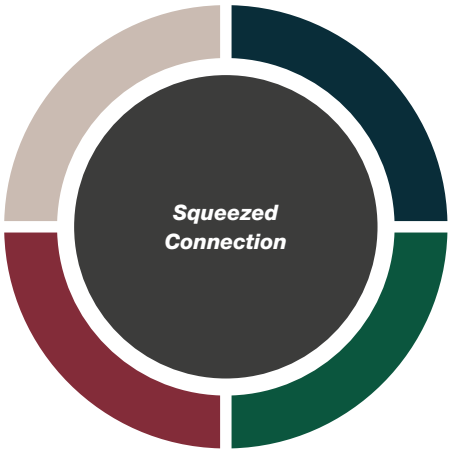
Nipple couplings consist of an additional threaded steel nipple that is pressed and welded into both ends of the pipe umbrella pipes. This connection type ensures that the second moment of inertia of the coupling is not lower than the second moment of inertia of the default pipe. The internal pipe diameter in the connection area is reduced.

This pipe connection type can be recommended for advances where enhanced static load-bearing capacity is required and settlement limitations are part of the design.

Comparison Pipe Connections

Criterion	Standard Threaded Connection	Squeezed Connection	Nipple Coupling
Connection type	Outside and inside thread is cut into the ends of the pipe umbrella pipes	Reduced pipe end force-fitted with its counter piece	Threaded steel nipple, pressed and welded into both ends of pipe umbrella pipes
Static influence	Significant reduction of pipe cross-section and section modulus in the thread connection area	Constant cross section and reduced section modulus in the coupling area	Second moment of inertia at the coupling is not lower than the second moment of inertia of the standard pipe
Elastic behavior	Stiffness and strength are considerably lower than those of standard pipes	Reduction of the stiffness against bending in the connection area	Stiffness and strength are adequate to standard pipes
Ultimate behavior	Rupture load of connections can be lower than elastic load of standard pipes	Ultimate load is higher than the elastic design load of a standard pipe (> 1.5)	Rupture load of connections higher than standard pipe
Recommended usage	Installation of measurement instrumentations or ground improving injections	Pipe umbrella with a designed static load-bearing capacity	Projects where settlement limitations are part of the design

Groundbreaking Technology



Enhanced Working Safety

- Remote-controlled operation allows a safe pipe connection
- Reduction of physical labor required
- No “hands on” during the pipe connecting working step
- Integrated drill rod wrench allows safe manipulation of drill stee

Conventional (Threaded) Installation	Squeezed Connection
Manual connection of MF pipe umbrella pipes: chain pipe wrench	Remote-controlled pipe connection using a hydraulic cylinder assembly
Manual connection and disconnection of MF drill rods: drill rod wrench	Centralized connection and remote-controlled drill steel disconnection
Direct exposure of personnel to moving drilling tools and hydraulic drifter	Limitation of personnel exposed to the operation range of the hydraulic hammer

Proven Cycle Time Savings

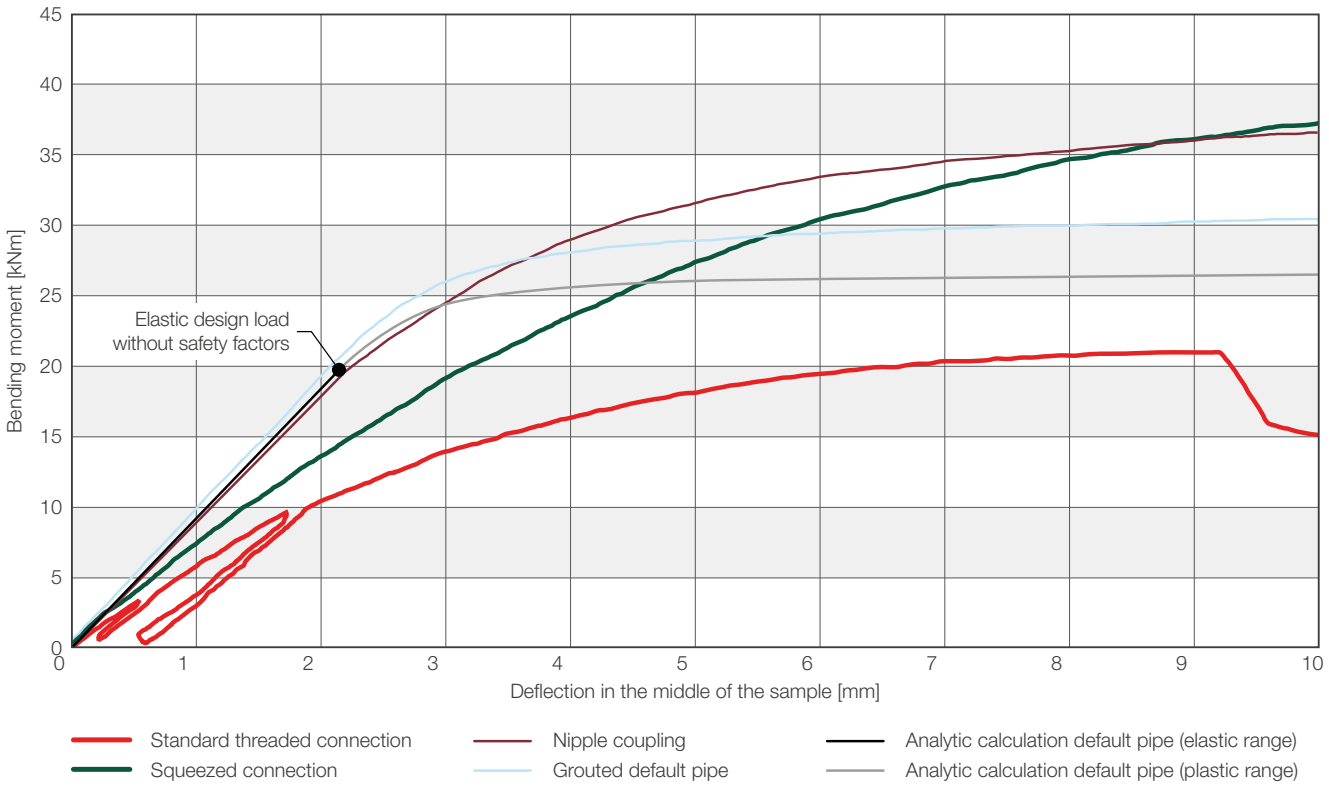
- Faster connection process than for standard threads
- Elimination of delays due to jammed or damaged pipes
- Total time savings of approx. 3 hours for an exemplary pipe umbrella (15 pipe umbrella drills, each 18 [m] long)
- Experience: 5% difficult threaded connections (outliers) which require additional handling time

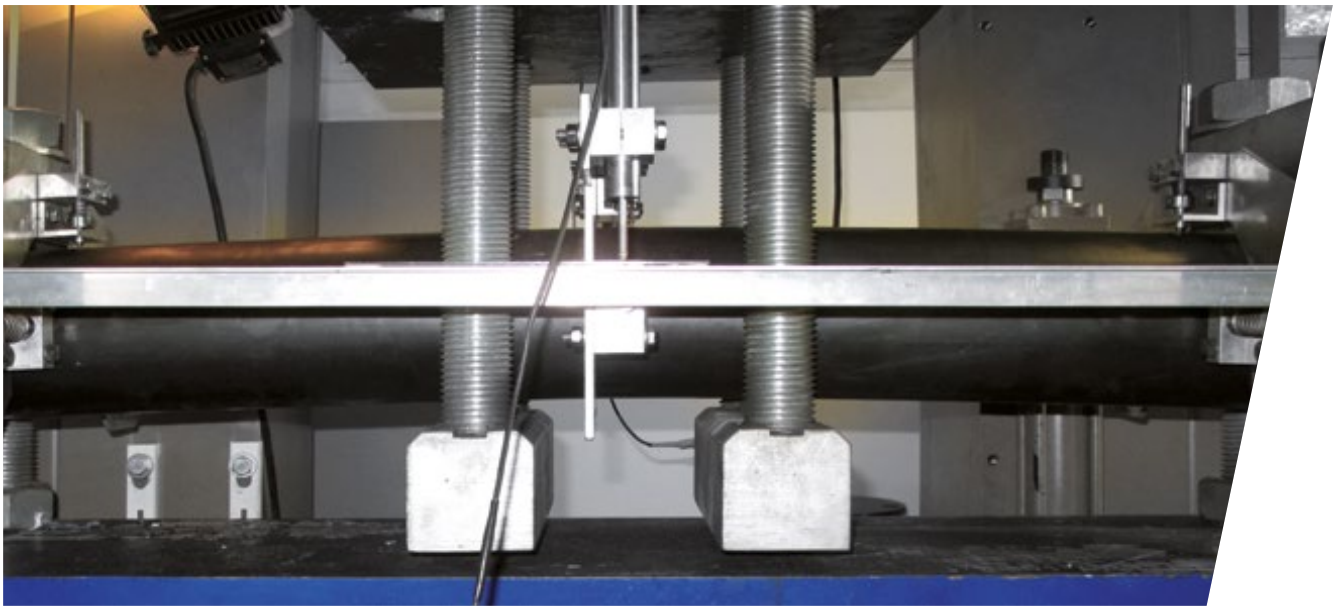
Parameter	Unit	Standard Threaded Connection	Squeezed Connection	Time Savings
No. of pipes	[1]	15		
Single pipe length	[m]	3		
Umbrella length	[m]	18		
No. of connections	[1]	75		
Single connecting time	[min]	3.5	1.5	2
Single delay time	[min]	10	0	10
No. of difficult connections	[1]	5%	0%	---
Total connecting time	[min]	262.5	112.5	150
Total delay time	[min]	37.5	0	37.5
Sum	**[min]**	**300**	**112.5**	**187.5**

Improved Load-Bearing Capacity

- Load-transfer based design criteria: Elastic and plastic moments of the pipe connection
- Design criterion 1: Maximum elastic moment My of the pipe connection is improved
- Design criterion 2: Significantly higher ultimate moment Mult of the pipe connection than the elastic design load (standard pipe)
- Example: Comparison pipe couplings AT – 114.3 x 6.3 [mm], steel grade S/E 355 (355 [N/mm²] or 51.5 [ksi])

Bending Tests: Comparison Pipe Couplings AT – 114.3 x 6.3 [mm]





Optimized Quality

Standard Threaded Connection	Squeezed Connection
Significant difference between default and calibrated pipes which are provided by DSI Underground	Error-free system
Sufficient thread strength extremely dependent on the quality of the threading	Verified quality for every single pipe connection
Additional impacts on the threads during installation	Robust system and high-strength pipe connection designed for the special demands of the construction industry

Utilization Rate

- Performance-based design approach
  - Enhanced load-bearing capacity allows reduction of pipe wall thickness compared to threaded connections
  - Significant material savings potential with simultaneous increase in performance
  - Lower transport weight increases efficiency of logistics
  - Easier handling procedures due to decreased weight of single umbrella pipes
  - Exemplary parameter study: AT – 139 Pipe Umbrella System with different connection types and wall thicknesses

Parameter	Unit	Standard Threaded Connection (Calibrated Pipes)		Squeezed Connection	Change Threaded to Squeezed Connection
Pipe dimensions	[mm]	139.7 x 8.0	139.7 x 10	139.7 x 6.3	
Unit weight	[kg/m]	26.0	32.0	20.7	-20% / -35%
Max. elastic moment M_y	[kNm]	14.1	18.4	20.4	+45% / +11%

Specifications SI Units

System [1]	Steel Grade [2]	Modulus of Elasticity	Yield Strength	Outer Diameter	Wall Thickness	Weight	Section Modulus	Second Moment of Area
Tipo		[N/mm²]	[N/mm²]	[mm]	[mm]	[kg/m]	[cm³]	[cm⁴]
AT – 76	E355 or S355	210.000	355	76.1	6.3	10.8	22	85
AT – 89				88.9	5.0	10.4	26	116
				88.9	**6.3**	**12.8**	**32**	**140**
				88.9	8.0	16.0	38	168
AT – 114				114.3	5.0	13.5	45	257
				114.3	**6.3**	**16.8**	**55**	**313**
				114.3	8.0	21.0	66	379
AT – 139				139.7	5.0	16.6	69	481
				139 .7	**6.3**	**20.7**	**84**	**589**
				139.7	**8.0**	**26.0**	**103**	**720**
				139.7	10.0	32.0	123	862
AT – 168				168.3	10.0	39.0	186	1,564
				168.3	12.5	48.0	222	1,868
				168.3	16.0	60.1	267	2,244

			Maximum Elastic Moment M_y [3]				Ultimate (Plastic) Moment M_{ult} [3]
System [1]	Outer Diameter	Wall Thickness	Standard Pipe	Nipple Couplings	Squeezed Connection	Threaded Connection (Calibrated Pipes)	Squeezed Connection [4]
Tipo	[mm]	[mm]	[kNm]	[kNm]	[kNm]	[kNm]	[kNm]
AT – 76	76.1	6.3	7.9	N/A	N/A	2.9	N/A
AT – 89	88.9	5.0	9.3	N/A	5.9	N/A	> 15
	88.9	**6.3**	**11.2**	**N/A**	**6.5**	**4.1**	**> 20***
	88.9	8.0	13.4	N/A	N/A	5.4	N/A
AT – 114	114.3	5.0	16.0	16.0	10.5	N/A	> 27*
	114.3	**6.3**	**19.4**	**19.3**	**12.1**	**6.9**	**> 35***
	114.3	8.0	23.6	19.3	13.2	9.3	> 35
AT – 139	139.7	5.0	24.4	24.4	17.5	N/A	> 44
	139.7	**6.3**	**29.9**	**29.9**	**20.4**	**10.4**	**> 50***
	139.7	**8.0**	**36.6**	**36.6**	**23.3**	**14.1**	**> 60***
	139.7	10.0	43.8	38.8	N/A	18.4	N/A
AT – 168	168.3	10.0	66.0	66.0	N/A	26.0	N/A
	168.3	12.5	78.8	69.7	N/A	33.5	N/A
	168.3	16.0	94.7	N/A	N/A	43.2	N/A

1) Deviating structural properties are available on request. Commonly used systems are bold marked. Non-applicable combinations (system and connection type) are indicated by “N/A”.
2) Steel grade S355 according to EN 10025-2 or E355 according to EN 10296-1. Alternatively, a carbon steel with a minimum yield strength of 355 [N/mm²] is required.
3) Values for M_y and M_{ult} are product-specific and verified by DSI Underground inspection certificates.
Laboratory test reports are available on request.
4) Values determined in the course of laboratory bending tests are indicated with an asterisk, all other ones are calculated.

Specifications US Cust. Units

System [1]	Steel Grade [2]	Modulus of Elasticity	Yield Strength	Outer Diameter	Wall Thickness	Weight	Section Modulus	Second Moment of Area
Tipo		[ksi]	[ksi]	[in]	[in]	[lb/ft]	[in^3]	[in^4]
AT – 76	E355 or S355	210.000	≥ 51.5	3.0	0.25	7.3	1.34	2.04
AT – 89				3.5	0.20	7.0	1.59	2.79
				3.5	**0.25**	**8.6**	**1.95**	**3.36**
				3.5	0.31	10.8	2.32	4.04
AT – 114				4.5	0.20	9.1	2.75	6.17
				4.5	**0.25**	**11.3**	**3.36**	**7.52**
				4.5	0.31	14.1	4.03	9.11
AT – 139				5.5	0.20	11.2	4.21	11.56
				5.5	**0.25**	**13.9**	**5.13**	**14.15**
				5.5	**0.31**	**17.5**	**6.29**	**17.30**
				5.5	0.39	21.5	7.51	20.71
AT – 168				6.6	0.39	26.2	11.35	37.58
				6.6	0.49	32.3	13.55	44.88
				6.6	0.63	40.4	16.29	53.91

			Maximum Elastic Moment M_y [3]				Ultimate (Plastic) Moment M_{ult} [3]
System [1]	Outer Diameter	Wall Thickness	Standard Pipe	Nipple Couplings	Squeezed Connection	Threaded Connection (Calibrated Pipes)	Squeezed Connection [4]
Tipo	[in]	[in]	[lbf·ft]	[lbf·ft]	[lbf·ft]	[lbf·ft]	[lbf·ft]
AT – 76	3.0	0.25	5,83	N/A	N/A	2,14	N/A
AT – 89	3.5	0.20	6,86	N/A	4,35	N/A	> 11,060
	3.5	**0.25**	**8,26**	**N/A**	**4,79**	**3,02**	**> 14,750***
	3.5	0.31	9,88	N/A	N/A	3,98	N/A
AT – 114	4.5	0.20	11,8	11,80	7,74	N/A	> 19,900*
	4.5	**0.25**	**14,31**	**14,23**	**8,92**	**5,09**	**> 25,800***
	4.5	0.31	17,41	14,23	9,74	6,86	> 25,800
AT – 139	5.5	0.20	18,00	18	12,91	N/A	> 23,450
	5.5	**0.25**	**22,05**	**22,05**	**15,05**	**7,67**	**> 36,880***
	5.5	**0.31**	**26,99**	**26,99**	**17,19**	**10,40**	**> 44,250***
	5.5	0.39	32,31	28,62	N/A	13,57	N/A
AT – 168	6.6	0.39	48,68	48,68	N/A	19,18	N/A
	6.6	0.49	58,12	51,41	N/A	24,71	N/A
	6.6	0.63	69,85	N/A	N/A	31,86	N/A

1) Deviating structural properties are available on request. Commonly used systems are bold marked. Non-applicable combinations (system and connection type) are indicated by "N/A".
2) Steel grade S355 according to EN 10025-2 or E355 according to EN 10296-1. Reference: carbon steel with a minimum yield strength of 51.5 [ksi].
3) Values for M_y and M_{ult} are product-specific and verified by DSI Underground inspection certificates. Laboratory test reports are available on request.
4) Values determined in the course of laboratory bending tests are indicated with an asterisk, all other ones are calculated.

Self-Drilling Installation Technology

Installation Method

The AT – Pipe Umbrella System is installed:

- Self-drilling
- Piecewise
- With conventional drilling machines
- By hydraulic, rotary-percussive drilling

Cooling, flushing, and backflow of the cuttings takes place inside the casing pipes by using water or an air-water mist. Self-drilling installation features the smallest possible stress relaxation due to an immediate support of the borehole wall during installation and an accurate installation due to a minimized annular gap.

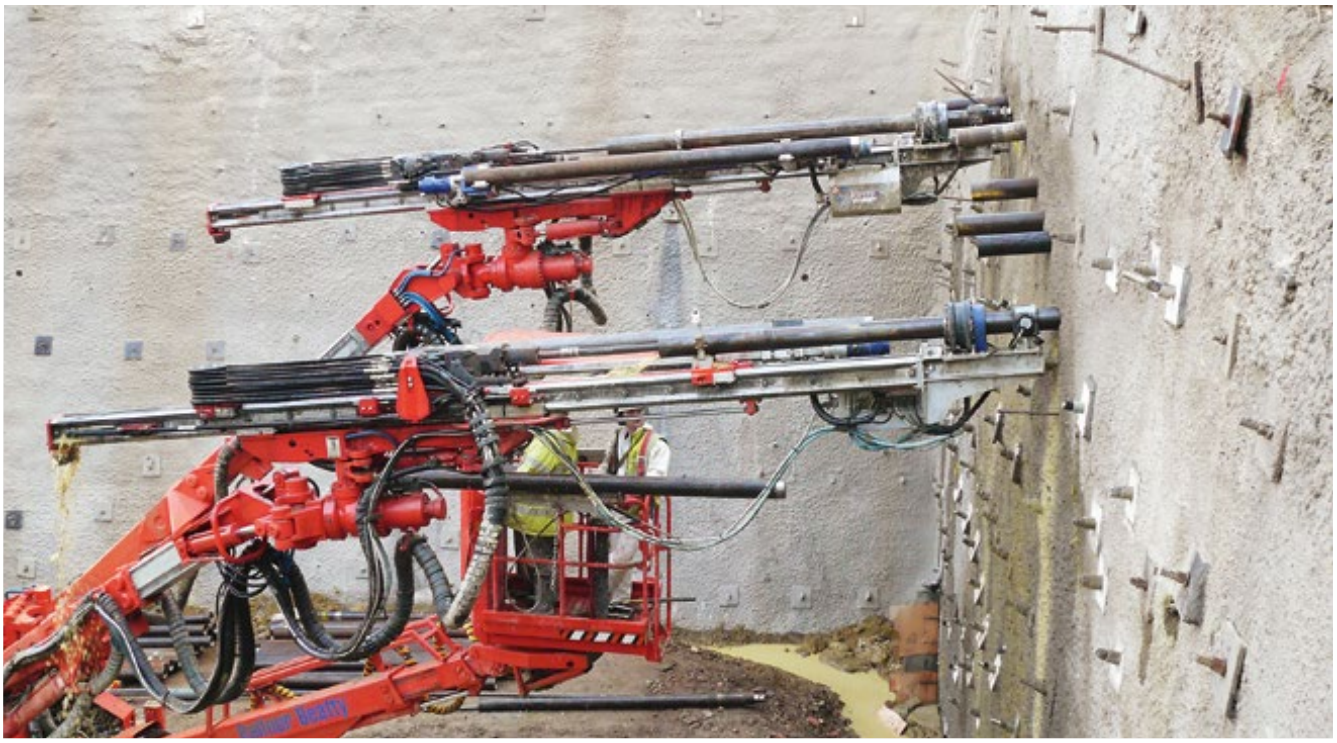
The length of piecewise installed pipe umbrella pipes can be adjusted according to project or machinery requirements.

Starter Unit

One important factor in the success of the AT – Pipe Umbrella Support System is the starter unit:

- Single-use full face drill bits ensure the same quality for each drilling process
- Stable drilling direction due to stable drill bit orientation
- Simple connection and disconnection of the drilling adapter
- Proven back-flushing of water inside umbrella pipes
- Loss or blocking of a drill bit is impossible – optimum pre-conditions for achieving the total drilling depth every time
- Starter unit (drill) bit can be adapted to given ground conditions

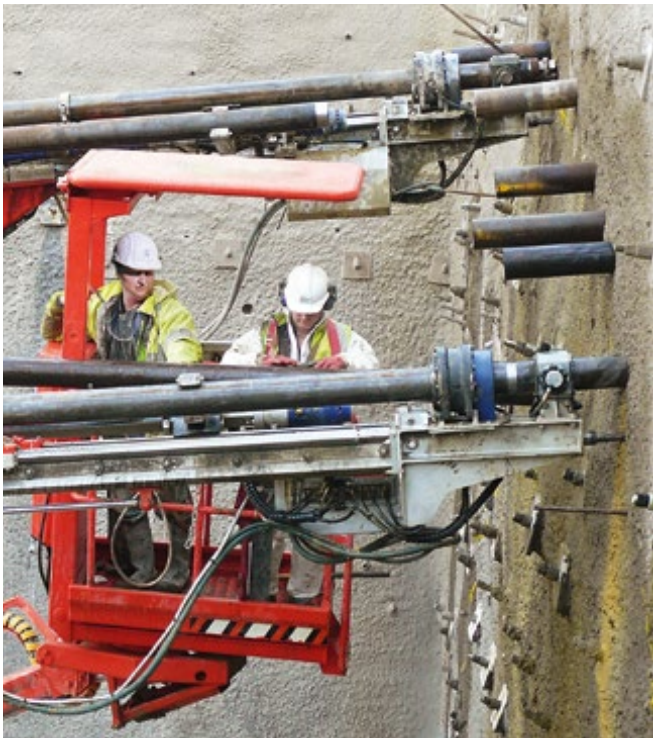
Installation Procedure Using the AT – Pipe Umbrella Automation Unit



1. For drilling, the AT – Starter Unit with drill bit is assembled onto the drill boom together with the first AT – Extension Tube, the AT – Adapter, and the drill rod.

2. Installation of the first AT – Extension Tube.

3. The next drill rod with AT – Extension Tube is connected to the previously installed pipe and the drilling process is continued. Reloading AT – Automation Unit (AT – Extension Tube and drill rod).



4. The last step is to be repeated until the designed length of the AT – Pipe Umbrella has been installed. Followed by removal of adapter and drill steel.

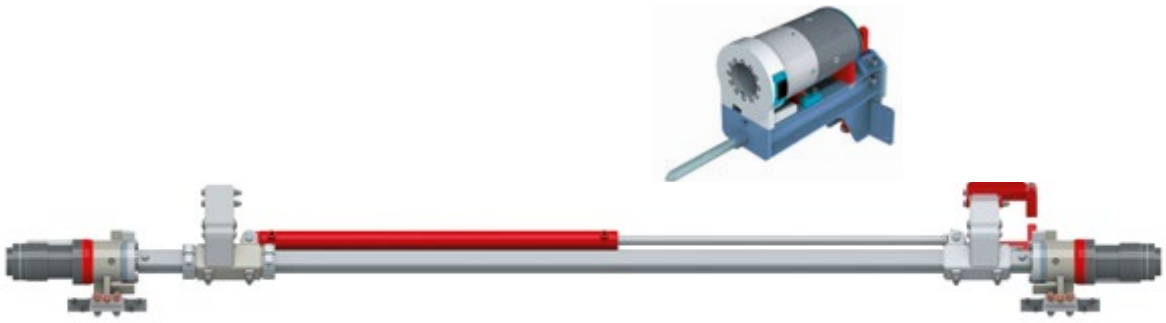
AT – Pipe Umbrella Automation Unit

Main Advantages

- Compatible with every standard drill jumbo
- Shorter manipulation times due to exact and mechanized feeding
- Faster construction of a pipe umbrella support system
- Higher occupational safety
- No handling in the vicinity of moving parts of the drilling machine
- Simple re-charging of extension pipes via a loading basket
- Remote-controlled feeding
- Less manpower required
- Optimum utilization of the working space
- Smaller saw-tooth shaped profile and thereby less excavation volume

Mechanized Installation – Selection of the Required Degree

Installation Mode / Characteristics	Pipe Connection Type	Degree of Mechanization	Mechanized Working Steps
Conventional installation	Threaded	0%	[–]
Threading Unit	Threaded	50%	Pipe connection, drill steel clamping (wrench)
Squeezing Unit	Squeezed	50%	Pipe connection, drill steel clamping (wrench)
AT – Automation Unit	Threaded or Squeezed	100%	Pipe connection, drill steel clamping (wrench), drill steel connection, pipe, and drill steel feeding

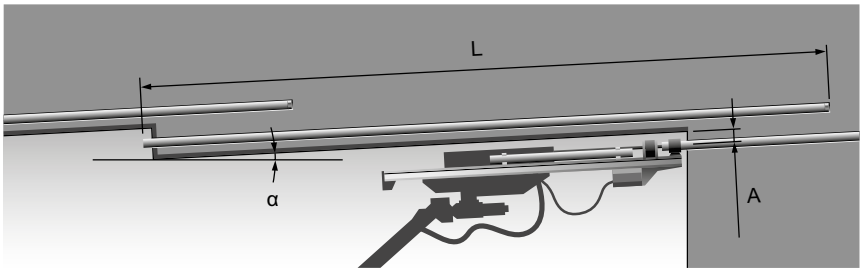


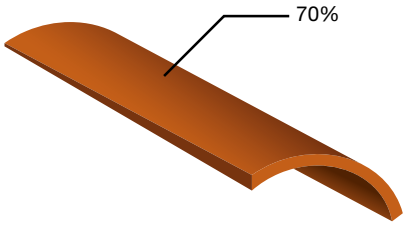
Comparison of Pipe Consumption and Over-Excavation

- Different pipe umbrella lengths, conventional and mechanized installation
- Top heading excavation with 6 [m] (19.5 [ft]) radius and 1 [m] (3.3 [ft]) advance length
- AT – 114 Pipe Umbrella, axial pipe distance 500 [mm] (19.5 [in]), overlap 3.5 [m] (11.5 [ft])

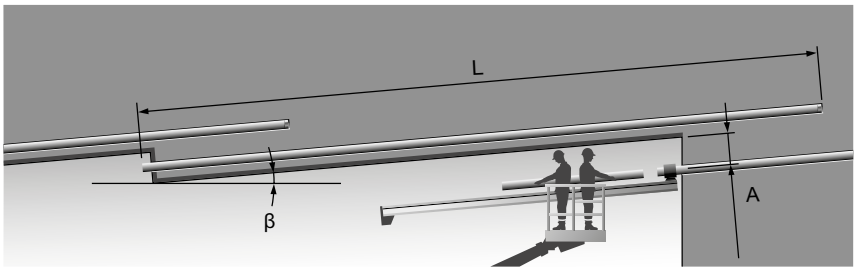
Pipe umbrella length L	Pipes per umbrella	Excavation steps per umbrella	Pipes installed per umbrella	Pipes installed per [m] tunnel		Mechanized Installation				Conventional Installation			
						Headroom A	Inclination α	Over-excavation sawtooth		Headroom B	Inclination β	Over-excavation sawtooth	
[m]	[1]	[1]	[m]	[m]	[%]	[mm]	[°]	[m³]	[m³/m]	[mm]	[°]	[m³]	[m³/m]
12		8	360	45.0	100%		6.0	63.1	7.9		8.1	89.2	11.2
15	30	11	450	40.9	91%	300	4.4	85.6	7.8	600	5.9	121.1	11.0
18		14	540	38.6	86%		3.5	108.1	7.7		4.7	153.0	10.9
[ft]	[1]	[1]	[ft]	[ft]	[%]	[in]	[°]	[ft³]	[ft³/ft]	[in]	[°]	[ft³]	[ft³/ft]
39.4		8	1,181	147.6	100%		6.0	2,228	279		8.1	3,15	394
49.2	30	11	1,476	134.2	91%	11,8	4.4	3,023	275	23.6	5.9	4,277	389
59.1		14	1,772	126.5	86%		3.5	3,818	273		4.7	5,403	386

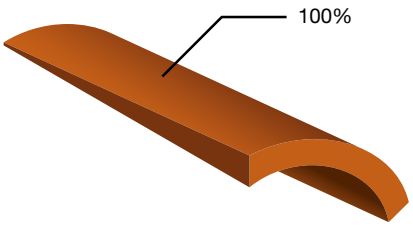
Mechanized Installation



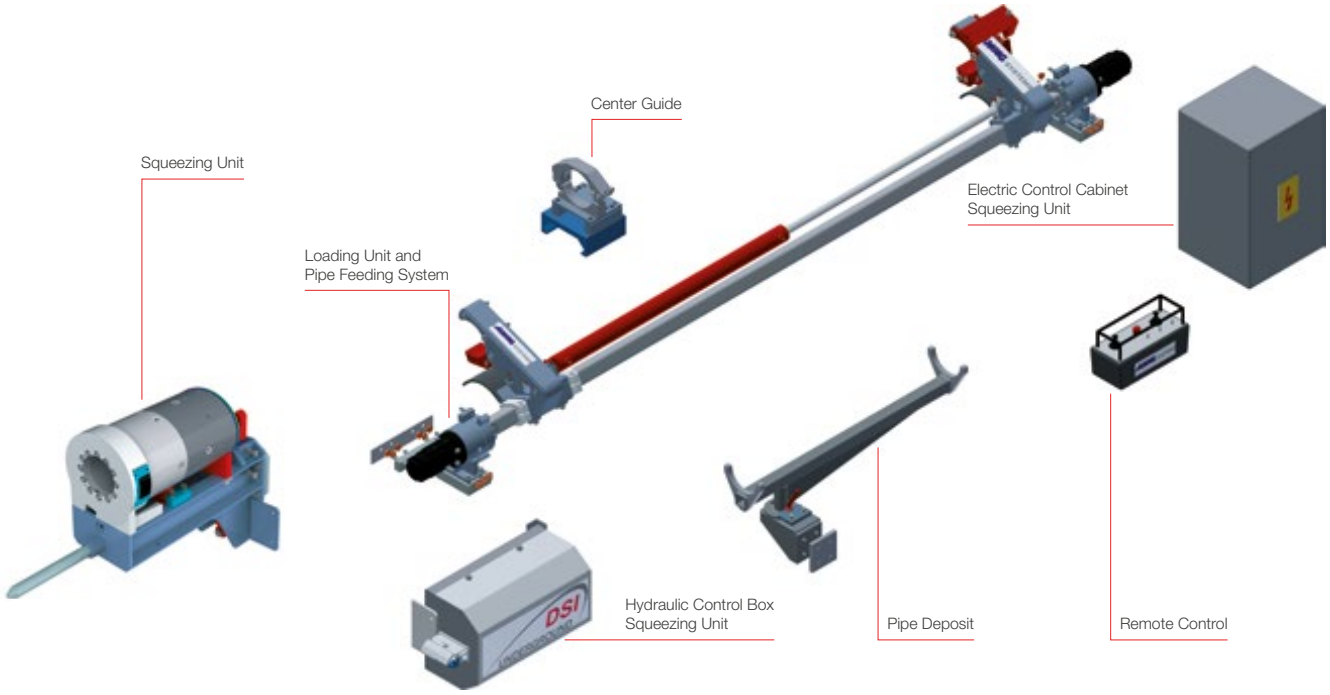


Conventional Installation





Assembly Groups – Squeezing Unit



Specifications SI Units

Characteristics / Assembly Group	Dimensions	Weight
	(L x W x H) [mm]	[kg]
Pipe deposit	1,040 x 230 x 350	28
Squeezing unit	1,165 x 380 x 750	200
Loading unit and pipe feeding system	3,650 x 460/780 x 430/570	160
Center guide	155 x 260 x 230	12
Hydraulic control box squeezing unit	550 x 275 x 345	60
Electric control cabinet squeezing unit	395 x 615 x 355	35
Remote control	250 x 140 x 180	2.3

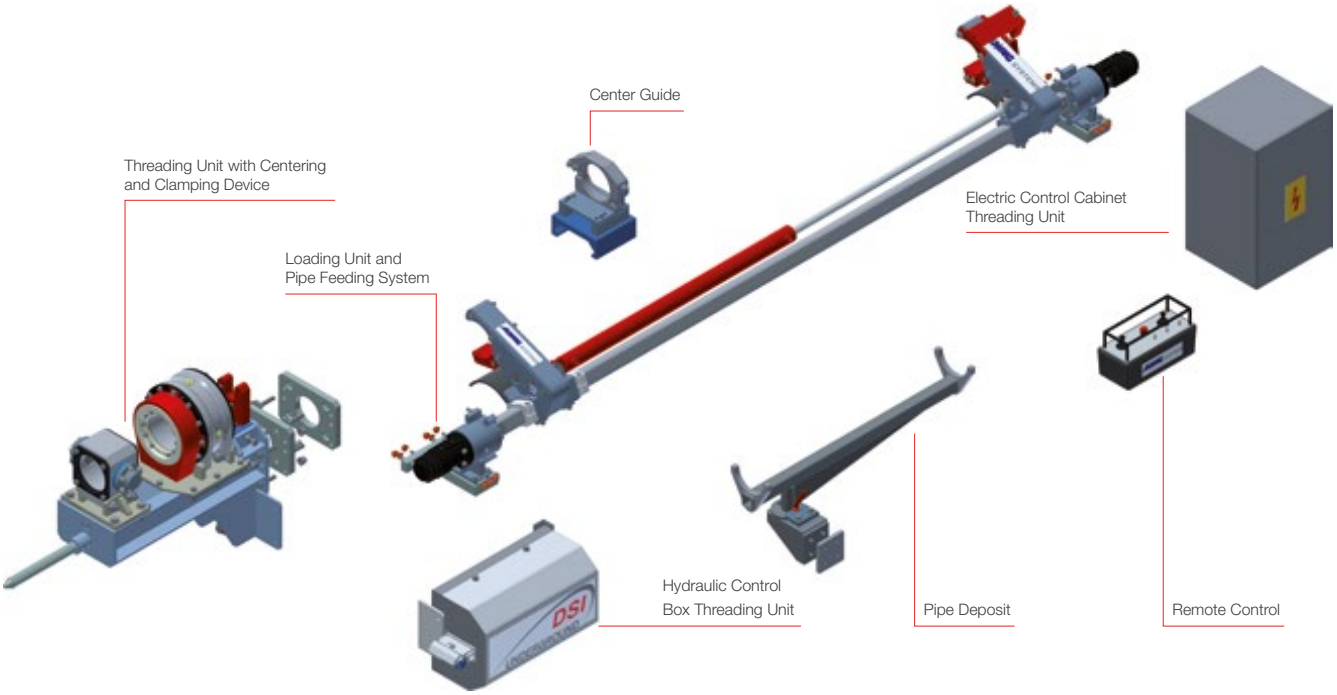
Characteristics	Unit	Value	Remarks
Total weight (gross)	[kg]	500 - 520	Deviations possible, depending on the type
Electric supply	[V]	24	DC
Hydraulic supply	[L/min]	20 - 25	At approx. 200 [bar]

Specifications US Customary Units

Characteristics / Assembly Group	Dimensions	Weight
	(L x W x H) [in]	[lb]
Pipe deposit	40.9 x 9.1 x 13.8	62
Squeezing unit	45.9 x 15.0 x 29.5	441
Loading unit and pipe feeding system	143.7 x 18.1/30.7 x 16.9/22.4	353
Center guide	6.1 x 10.2 x 9.1	27
Hydraulic control box squeezing unit	21.6 x 10.8 x 13.8	133
Electric control cabinet squeezing unit	15.6 x 24.2 x 14.0	77
Remote control	9.8 x 5.5 x 7.1	5

Characteristics	Unit	Value	Remarks
Total weight (gross)	[lb]	1,100 - 1,150	Deviations possible, depending on the type
Electric supply	[V]	24	DC
Hydraulic supply	[gal/min]	5.3 - 6.6	At approx. 2,900 [psi]

Assembly Groups – Threading Unit



Specifications SI Units

Characteristics / Assembly Group	Dimensions	Weight
	(L x W x H) [mm]	[kg]
Pipe deposit	1,040 x 230 x 350	28
Threading unit with centering and clamping device	1,165 x 370 x 740	160
Loading unit and pipe feeding system	3,650 x 460/780 x 430/570	160
Center guide	155 x 260 x 230	12
Hydraulic control box threading unit	550 x 275 x 345	60
Electric control cabinet threading unit	395 x 615 x 355	35
Remote control	250 x 140 x 180	2.3

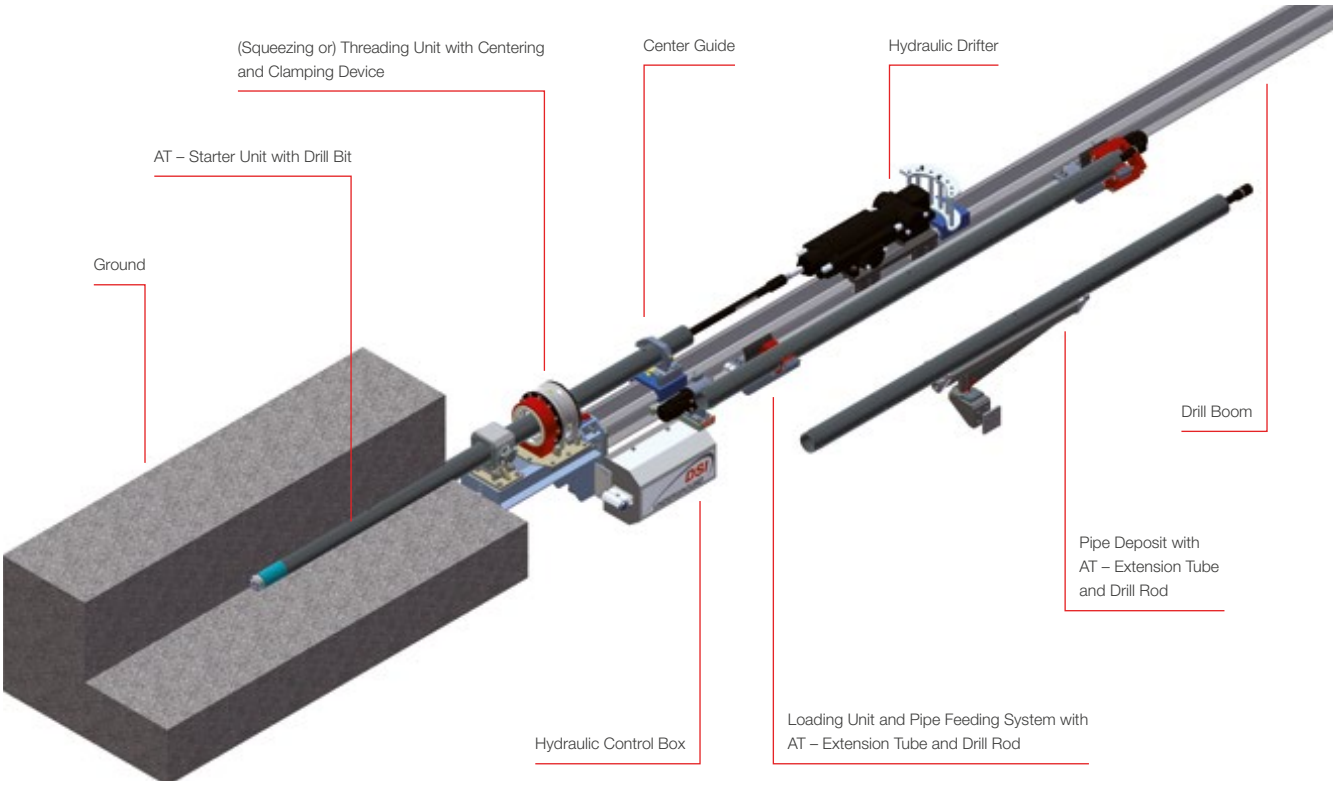
Characteristics	Unit	Value	Remarks
Total weight (gross)	[kg]	460 - 490	Deviations possible, depending on the type
Electric supply	[V]	24	DC
Hydraulic supply	[L/min]	15 - 20	At approx. 170 [bar]

Specifications US Customary Units

Characteristics / Assembly Group	Dimensions	Weight
	(L x W x H) [in]	[lb]
Pipe deposit	40.9 x 9.1 x 13.8	62
Threading unit with centering and clamping device	45.9 x 14.6 x 29.1	353
Loading unit and pipe feeding system	143.7 x 18.1/30.7 x 16.9/22.4	353
Center guide	6.1 x 10.2 x 9.1	27
Hydraulic control box threading unit	21.6 x 10.8 x 13.8	133
Electric control cabinet threading unit	15.6 x 24.2 x 14.0	77
Remote control	9.8 x 5.5 x 7.1	5

Characteristics	Unit	Value	Remarks
Total weight (gross)	[lb]	1,010 - 1,080	Deviations possible, depending on the type
Electric supply	[V]	24	DC
Hydraulic supply	[gal/min]	4.0 - 5.3	At approx. 2,500 [psi]

Mounted Assembly Groups



Accessories

- Injection flow-pressure meter
- Injection packer
- Grout mixing pump
- DYWI® Inject Systems
- Fishing tab
- Drill rod wrench
- Chain pipe wrench
- Online chain inclinometer measurements
- Online fiber glass measurements
- Rock drilling equipment: shank adapter, coupling, and coupling adapter



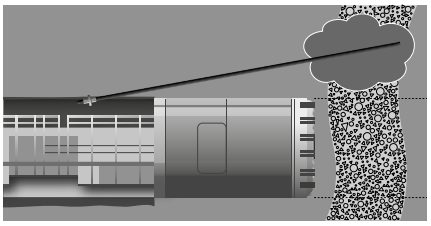







Mechanized Tunneling

The AT – Pipe Umbrella Support System can be combined with fiberglass or PVC extension pipes for application in mechanized Tunneling.

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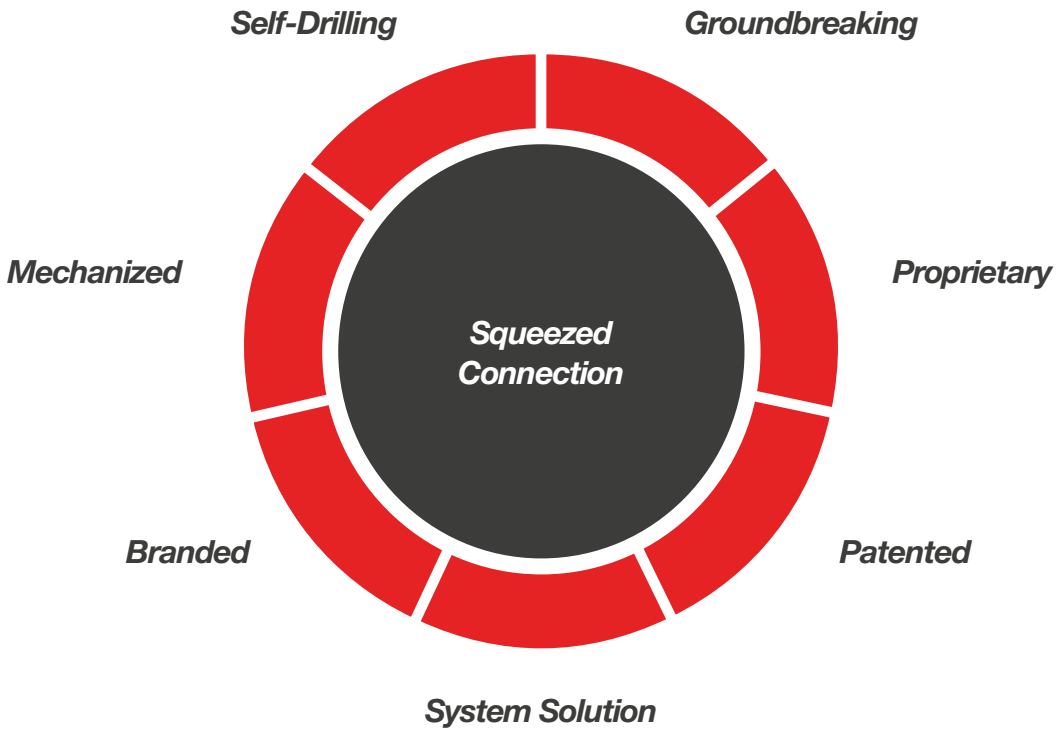
- AT – Pipe Umbrella geometry calculator
- Installation manual for the AT – Pipe Umbrella System

AT – Pipe Umbrella System at a Glance



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