A SUPER MICROPILE: WHERE ARE THE LIMITS OF MICROPILES?

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ABSTRACT

A micropile is a drilled and grouted, non-displacement pile with a small-diameter (typically less than 300 mm) that is typically reinforced by a steel load bearing element. Due to the small pile diameter, micropiles can withstand relatively significant axial loads and moderate lateral loads. The loads are primarily transferred through friction from the steel reinforcement to grout, and then to the ground in the micropile bond zone. The end-bearing contribution to the external load bearing capacity is usually neglected.
Among the different micropile typologies, self-drilling micropiles have been proven to be a very versatile solution and are, since their first development in the 80´s, increasingly used in deep foundation projects, both for the construction of new infrastructure and as reinforcement to retrofit existing structures.
The use of self-drilling micropiles allows a flexible use of the drilling equipment, enabling the installation of long micropiles even in confined spaces, obtaining high drilling performances associated to very low vibrations.
To the date, the common range of internal load bearing capacities from self-drilling micropiles lays between 150kN – 3200kN, depending on the steel sections, usually comprised between 300 – 6000 mm^2. Size and especially load bearing capacity could be considered limited, compared to other deep foundation technologies (i.e. bored or driven piles). Following the rapid development in the construction industry, especially supported by the development of more efficient high-performance drilling rigs, a new super micropile, the TITAN 196-130 was conceived to provide a self-drilling solution with an internal load bearing capacity of approx. 6500kN, able to be installed with available drilling rigs.
The following article presents the new development, as well as the experience gained in the installation tests. Furthermore, a brief economic analysis will be presented, based on the comparison between the use of a bored pile, a group of micropiles and a single high-performance micropile. Finally, different application fields will be discussed.

1. SI CONVERSION FACTORS

Table 1. Approximate conversions from SI Units

Dimension	Symbol	When you know	Multiply by	To Find	Symbol
Length	cm	centimeters	0.394	inches	in
	m	meters	3.281	feet	ft
Force	kN	kilonewtons	224.81	poundforce	lbf
	MN	meganewtons	224.81	kilopoundforce	kip
Pressure	Bar	bars	0.01	kilopoundforce/square inch	ksi
Stresses	kPa (kN/m^2)	kilopascals	0.145	Poundforce/square inch	psi
	MPa (MN/m^2)	megapascals	145	Poundforce/square inch	psi

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1. INTRODUCTION

Micropiling is one of the most successfully implemented deep foundation technologies. According to (FHWA, 2005), a micropile is a drilled and grouted, non-displacement pile with a small-diameter (typically less than 300 mm) that is typically reinforced. Due to the small pile diameter, micropiles can withstand relatively significant axial loads and moderate lateral loads. The loads are primarily transferred through friction from the steel reinforcement to grout, and then to the ground in the micropile bond zone. The end-bearing contribution to the external load bearing capacity is usually neglected. In Europe, the execution of micropiles is regulated by the harmonized standard EN 14199:2015. Among different micropile typologies, self-drilling micropiles have been proven to be a very versatile solution and are increasingly used, both for the construction of new infrastructure and as reinforcement to retrofit existing structures.
Self-drilling micropiles consist of continuously threaded hollow bars, made out of seamless steel pipes, installed via rotary percussive drilling. During the drilling process, the micropiles are continuously grouted (dynamic injection), building a rough interlocking at the interface grout-soil, increasing the skin friction (Fig. 1).

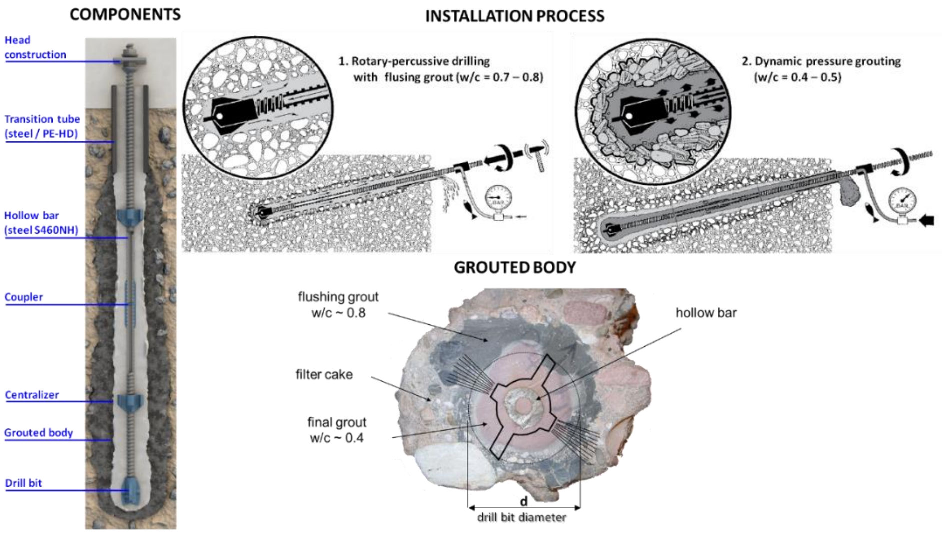


Fig. 1 Self-drilling micropiles: components, installation and grouted body (Lopez & Severi, 2017)

The use of self-drilling micropiles allows a flexible use of the drilling equipment, enabling the installation of long micropiles even in confined spaces, obtaining high drilling performances associated to very low vibrations.
It is due to their flexible installation process that the use of self-drilling micropiles can be considered as a cost-effective alternative to other deep foundation technologies, such as large size piles (bored, driven or displaced), which require large and heavy equipment that doesn´t always fit in in areas with restricted access and/or limited working space (typical conditions for intra-urban interventions).
Following the rapid development in the construction industry, especially supported by the development of more efficient high-performance drilling rigs, but also as result of more and more acceptance of hollow bar micropiles, larger hollow bar sizes have been developed to obtain higher resistances, in order to transfer the acting loads to less single elements. Several self-drilling micropile systems are available, with a common range of internal load bearing capacities between 150kN – 3200kN, depending on the steel sections and grades.

The present article describes the development of the TITAN 196-130, which was conceived to provide a self-drilling solution, with a much higher internal load bearing capacity and able to be installed with available drilling rigs.

2. DEVELOPEMENT

The TITAN 196-130 was developed to evaluate the limits of current technological means, both regarding production and installation. The aim was to answer following questions:

- Is it possible to produce a hollow bar, whose resistance doubles the current maximum available capacities using existing production units?
- Is it possible to produce the correspondent accessories (coupling nut, collar nut, drill bit, etc.)?
- Is it possible to install the self-drilling system using available drilling equipment?

2.1 <u>Production</u>

The production trials began in 2015 at the Friedr. Ischebeck GmbH facilities in Ennepetal, Germany. To obtain the aimed load bearing capacity of approx. 6400kN, steel pipes 193x32 (S460NH) were chosen. The geometric properties of the produced hollow bars and accessories are presented in the following tables:

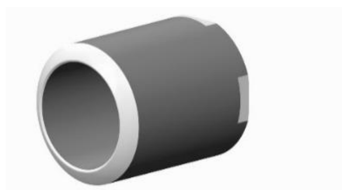
Table 2. Geometrical properties of the TITAN 196-130 hollow bars

Raw material	Steel pipe 193x32	
Steel grade	S460NH	
Outer diameter (OD) (mm)	196	
Inner diameter (ID) (mm)	130	
Length (m)	3.0	
Thread direction	Right-handed	
Cross section (mm^2)	16077	
Weight (kg/m)	127.3	

Table 3. Geometrical properties of the coupling nut

Raw material	Steel pipe 254x36	
Steel grade	S460NH	
Outer diameter (OD) (mm)	254	
Inner diameter (ID) (mm)	198	
Length (m)	0.6	
Thread direction	Right-handed	
Weight (kg)	101.5	

Table 4. Geometrical properties of the collar nut

Raw material	Steel pipe 254x36	
Steel grade	S460NH	
Outer diameter (OD) (mm)	254	
Inner diameter (ID) (mm)	198	
Length (m)	0.3	
Thread direction	Right-handed	
Weight (kg)	49	

2.2 Load bearing capacity

Tensile load tests were carried out at the Material Test Establishment (*MPA*) in Hannover, Germany to obtain the mechanical parameters of the hollow bars. A 10 MN-testing machine was used to perform the tests according to ISO 6892-1 (Fig. 2, left).

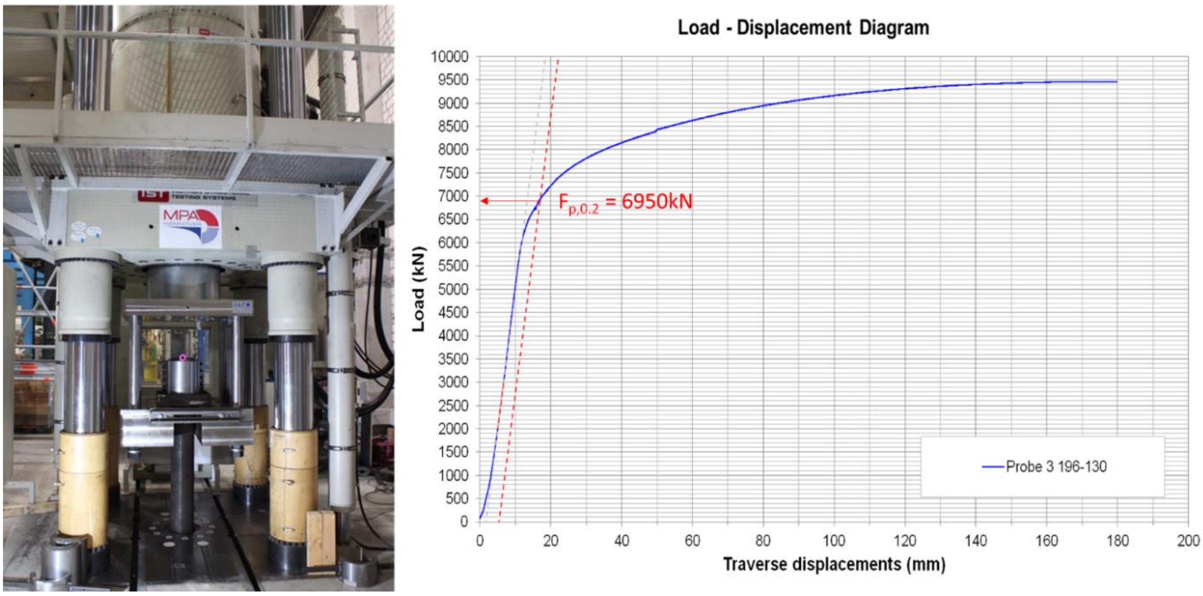


Fig. 2 Load tests (tension) of the TITAN 196-130 hollow bars

Fig. 2 (right) shows an exemplary Load-Displacement Diagram. The results of the load tests are summarized in Table 5. The obtained (characteristic) load bearing capacity of the hollow bars exceeded the aimed value of 6400kN.

Table 5. Results of the load tests (tension)

Test samples	TITAN 196-130
Outer diameter (OD) (mm)	196
Inner diameter (ID) (mm)	130
Sample length (m)	2.5
Average cross section (mm^2)	16077
Sample weight (kg)	315
Average yield load (at 0.2%-elongation) $F_{p,0.2}$ (kN)	6872
Characteristic (5%-fractal) load bearing capacity $F_{p,0.2k}$ (kN) (According to EN 1990:2002, Annex D)	6465
Average yield strength (at 0.2%-elongation) $R_{p,0.2}$ (MN/m^2)	427
Average maximum load F_m (kN)	9601
Elongation at maximum load A_{gt} (%)	9.5
Average tensile strength R_m (MN/m^2)	597
Ratio R_m / $R_{p,0.2}$ (-)	1.4

2.3 Installation and equipment

Drilling trials were carried out in March 2018 at the Friedr. Ischebeck GmbH facilities in Ennepetal, Germany by the Co. Neidhardt Grundbau GmbH (Hamburg, Germany). The location of the trials is presented in Fig. 3:

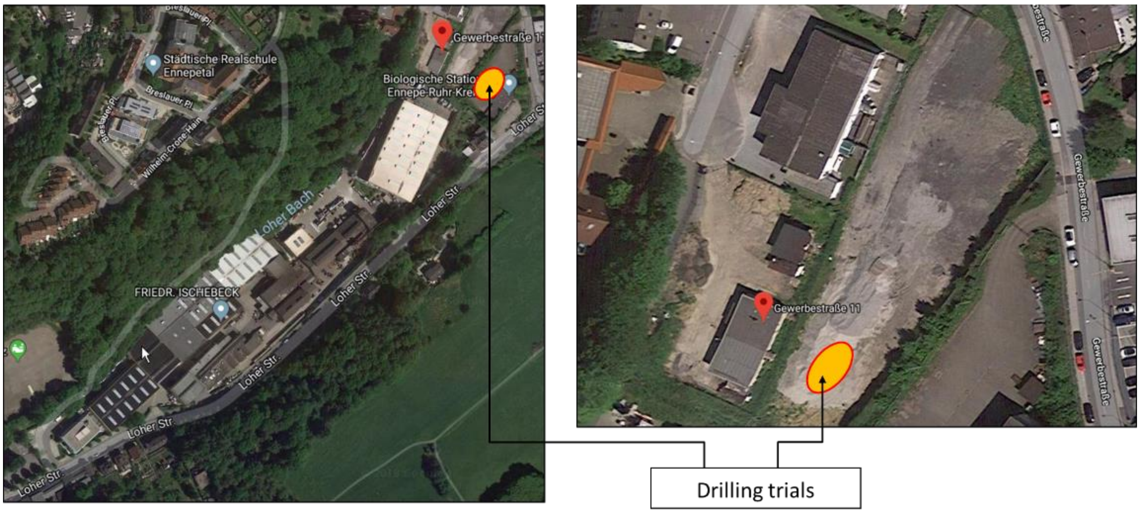


Fig. 3 Location of the drilling trials

Table 6 and Fig. 4 present an overview of the equipment used for the drilling trials:

Table 6. Equipment used for the drilling trials

Drill rig	Casagrande C8-2
Weight (kg)	21680
Mast length (m)	7.0
Drifter	Klemm KD 1828R
Torque (Nm)	7000
Single blow energy (Nm)	900
Blow frequency (blow/min)	2100
Piston weight (kg)	28
Excavator with hydraulic manipulator	IMB GMA 250
Weight (kg)	5000
Grouting station (mix-pump-unit)	Scheltzke MPS 100
Flow rate (liter/min)	170
Pressure (bar)	Up to 20 (for flow rate =170 liter/min)
Weight (kg)	2450

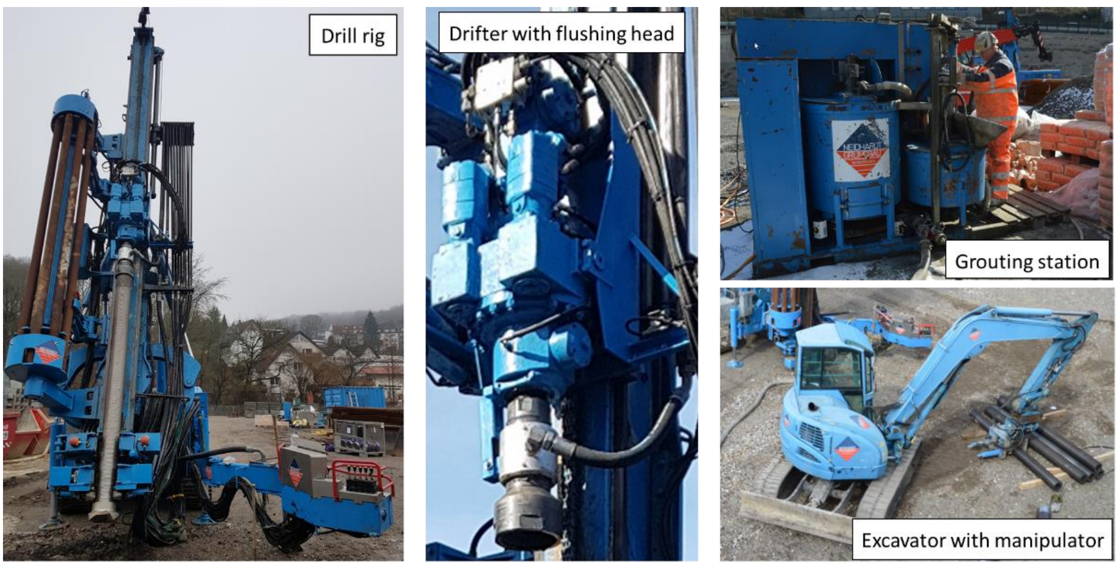


Fig. 4 Equipment used for the drilling trials

The subsoil in the area consists mainly of a granular infill, underlaid by claystone formations with different weathering grades. The hardness of the claystone increases with the depth.
During the trials, four (4) drillings with a length up to 24m were conducted. The ground conditions at the trial site are schematically presented in Fig. 5:

Fig. 5 Ground conditions at the trial site

Three types of drill bits were used during the trials, as shown in Fig. 6:

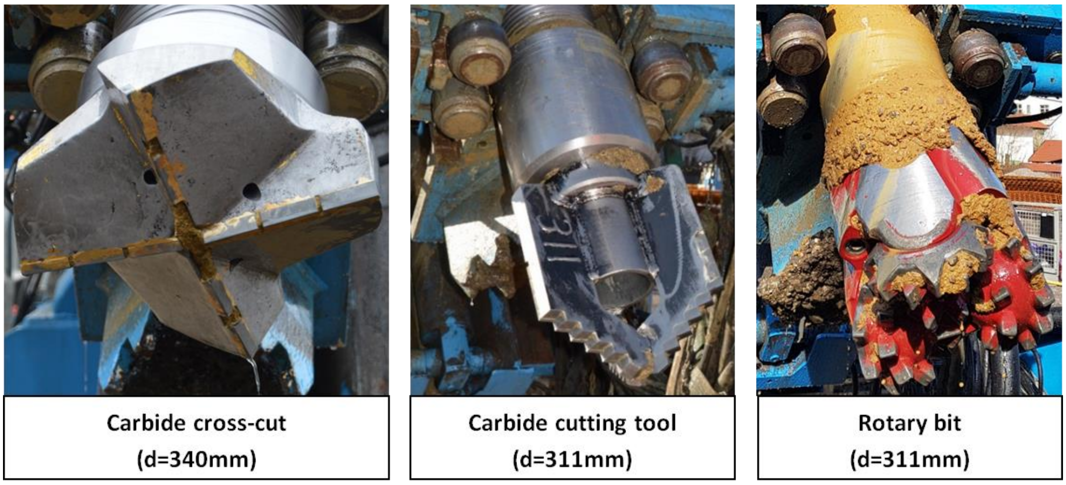


Fig. 6 Drill bits used during the trials

During the drilling trials, a maximum depth of 24m was reached, limited mainly by the capacity of the available equipment:

- The drifter reached its maximum torque capacity (7000Nm)
- The grouting station reached its maximum handling capacity for the combination flow rate – pressure, required to ensure a continuous flushing process with a cement grout (w/c ≈ 0.8)

After reaching the maximum depth, the assembled "drilling rod" was extracted. No signs of damage were observed at the hollow bars and coupling nuts. The carbide cross-cut drill bits showed only little abrasion, while the other drill bits reveled more signs of wear. The results of the drilling trials are summarized in Table 7.

Table 7. Summary of the drilling trials

Test Number	**1**	**2**	**3**	**4**
Maximum length (m)	24	24	24	24
Drilling process	rotary (0m – 6m) rotary-percussion (6m - 24m)	rotary (0m – 6m) rotary-percussion (6m - 24m)	rotary (0m – 12m) rotary-percussion (12m - 24m)	rotary-percussion (0m - 24m)
Total drilling time (hours)	3	3 - 4	3 - 4	3
Average drilling ratio (minutes / m)	2´10"	3´55"	2´50"	2´20"
Flushing fluid	Cement grout (w/c = 0.7 - 0.8)			
Injection pressure (bar)	6 - 10	10	5 -15	5 - 18
Grout consumption (m^3)	3	2.5	2.5	3
Drill bit	Carbide cross-cut	Rotary bit	Carbide cutting tool	Carbide cross-cut
Drill bit diameter (mm)	340	311	311	340
Borehole diameter (mm) (meas. at the surface)	390	360	360	360

3. SCOPE OF APPLICATION

As previously described, the motivation for the development was to provide a high-performance, self-drilling single element as an alternative to conventional bored piles (also known as drilled shafts), where high capacities are demanded but the access to the construction sites or the space for the drilling operations are restricted, conditions typically found in urban environments.
To evaluate if the above mentioned application field is technically and economically feasible, the use of a TITAN 196-130 was compared to a single large cast-in-place bored pile (D=0.8m) and to a group of smaller micropiles (TITAN 103/51). For the comparisons, the ground conditions at the trial site were considered.

3.1 Estimation of the load bearing capacity acc. to the German practice

The load bearing capacities of both the bored pile (D=0.8m) and the TITAN 196-130 were estimated using an analytical model, in concordance with the German practice and in compliance with the current European regulations for geotechnical design, the Eurocode 7 (EN 1997-1, 2010), and the Recommendations on Piling (*EAP*) published by the German Geotechnical Society (DGGT, 2012).
In the case of bored piles, the characteristic pile resistance ($R_{c,k}$), can be obtained from the tip or base resistance ($R_{b,k}$) and the shaft resistance ($R_{s,k}$):

$$R_{c,k} = R_{b,k} + R_{s,k} \qquad [1]$$

$$R_{b,k} = \frac{\pi}{4} * D^2 * q_{b,k} \quad [2]$$
$$R_{s,k} = \pi * D * \sum(q_{s,ki} * L_l) \quad [3]$$

Both the base and the shaft resistance are dependent of the pile settlements (s). According to (DGGT, 2012), the base and shaft resistance can be obtained from the pile geometry, the characteristic base pressure ($q_{b,k}$) of the load bearing stratum for settlements corresponding to 2%, 3% and 10% of the pile diameter (D) and the characteristic skin friction ($q_{s,k}$) of the surrounding soils, which increases linearly with the settlements until a limit value (s_{sg}) is reached:

$$s_{s,g} = 5x10^{-4} * R_{s,k\,(s_{s,g})}\ [in\ kN] + 0.5\ cm \leq 3cm \quad [4]$$

As friction elements, the characteristic micropile resistance ($R_{c,k}$) is obtained from the shaft resistance ($R_{s,k}$) only (equations [3] and [4]), usually neglecting the contribution of the base resistance ($R_{b,k} = 0$).
It is worth mentioning that an extensive, calibrated database of empirical values is provided for both the base pressure and skin friction for bored piles and micropiles, in dependence of the average penetrometer (CPT) tip resistance (q_c) for non-cohesive soils, the undrained shear strength for cohesive soils ($c_{u,k}$), and the unconfined compressive strength ($q_{u,k}$) for rocks and cemented soils.

3.2 Comparison with a bored pile (drilled shaft) and with a group of micropiles

Based on the information available, the parameters listed in Table 8 were adopted to evaluate the load bearing behavior of the bored pile and the micropiles:

Table 8. Adopted parameters for the analysis

Layer	Description	Bored piles		Micropiles
		Base pressure $q_{b,k}$ (kN/m^2)	Skin friction $q_{s,k}$ (kN/m^2)	Skin friction $q_{s,k}$ (kN/m^2)
1	Granular infill, loosen - medium dense	700	40	70
2a	Claystone Moderately weathered, moderately hard	3000	300	400
2b	Claystone weathered, weak	2000	200	250
2c	Claystone Moderately weathered, hard	3500	350	450
2d	Claystone Partially weathered, hard	4000	400	500

Parameters for bored piles acc. to (DGGT, 2012)
Parameters for micropiles acc. to (DGGT, 2012) and (Witt, 2009)

Considering a design compressive load E_d = 5400kN and using the parameters listed on Table 8, the load bearing capacity of a bored pile, the TITAN 196-130 and a group of micropiles (3) TITAN 103-51was obtained. The results are summarized as follows:

Table 9. Design summary

	Bored pile	TITAN 196-130	Group of 3 x TITAN 103-51	
			Single micropile	Group
Design action E_d (kN)	5400	5400	1800	5400
Diameter D (m)	0.8	0.36	0.2	--
Drill bit / Diameter d (mm)	--	Cross-cut / 340	Tri-wing / 175	--
Length L (m)	13.5	21	16	48
Base resistance $R_{b,k}$ (kN)	1759	0	0	0
Shaft resistance $R_{s,k}$ (kN)	6019	7645	2671	8013
Total resistance $R_{c,k}$ (kN)	7779	7645	2671	8013
Partial safety factor for resistance (comp) γ_p	1.4			
Design resistance $R_{c,d}$ (kN)	5556	5461	1907	5723
Internal load bearing capacity $R_{M,k}$ (kN) acc.to (DIBt, 2018)	--	6465	2500	--
Partial safety factor for material resistance γ_M	--	1.15		--
Design Load bearing capacity $R_{M,d}$ (kN)		5621	2173	
Verifications: $R_{c,d} \geq E_d$, $R_{M,d} \geq E_d$	OK	OK	OK	OK

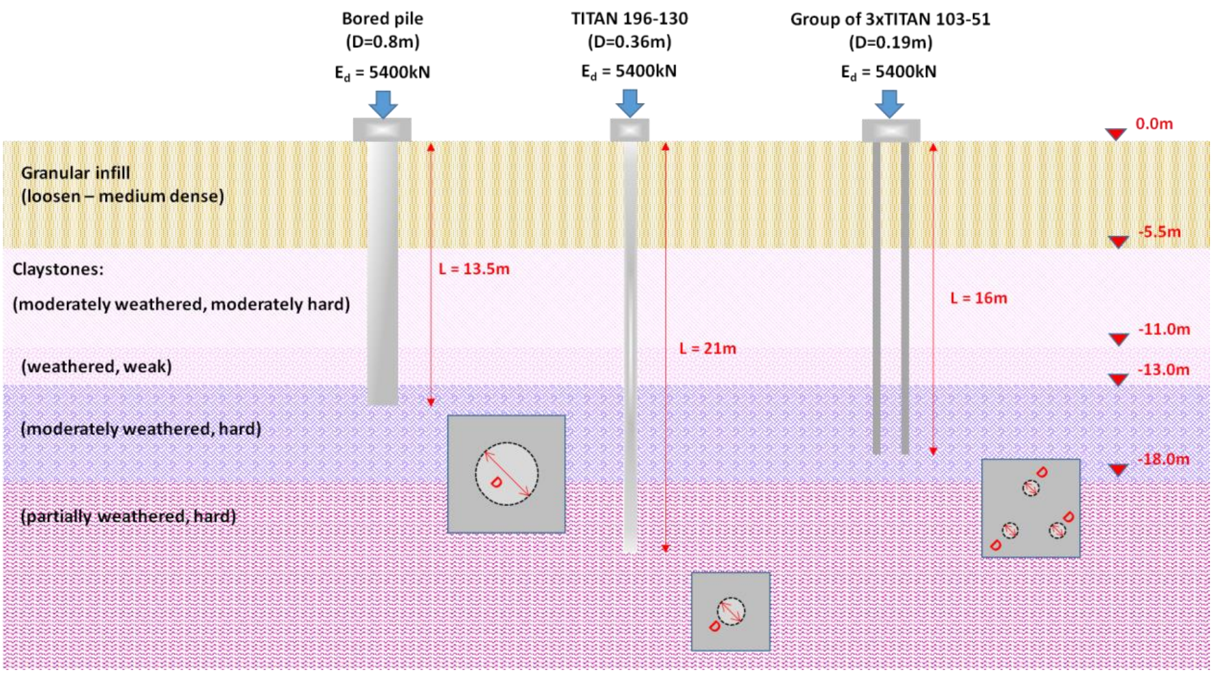


Fig. 7 Design summary

For the described ground conditions, the required lengths to resist the design action of 5400kN were obtained for a single high-performance micropile TITAN 196-130, a large size bored pile (D=0.8m) and a group of three micropiles TITAN 103-51.

Compared to the bored pile, the use of the TITAN 196-130 can reduce dramatically the equipment costs (operation and transport to the construction site), since a very large rig (i.e. BG 18 or larger) would be required to drill the 0.8m-big shaft, eventually using a temporary steel casing or a stabilizing suspension (bentonite or polymers), due to the weathering of the claystone. Even though the constitutive materials of the bored pile (self-compacting concrete and the reinforcement cage) are definitely less expensive than the steel for the TITAN 196-130, the installation time of the latter (about 2.5 hours for one 21m-long micropile) is considerably shorter than the installation time for a bored pile, which ranges from 5 to 8 hours per pile, if drilling with polymers or with a temporary steel casing, respectively.
Compared to a group of three TITAN 103-51, the use of the TITAN 196-130 reduces the total installation length from 48 linear meters (3 x 16m) to 21 m. Considering that the drilling rig required for the installation of the TITAN 196-130 is commonly used to install the smaller micropiles, the use of a single high-performance micropile can optimize the drilling operation time considerably.

4. SUMMARY AND CONCLUSIONS

The present document described the motivations for the development of a high-performance self-drilling micropile, the TITAN 196-130, with twice the load bearing capacity of existing available hollow bars.
As the result of the different conducted tests show, the production and installation of the TITAN 196-130 can be performed using available equipment, expanding the capabilities of the existing technological means.
Depending on the ground conditions, the use of a single TITAN 196-130 can be an advantageous alternative to replace large-size bored piles. Even though material costs show large differences, making cast-in-place concrete piles cheaper, the logistic and operative costs can be clearly reduced using a high-performance self-drilling micropile, which can be flexibly installed even in areas with restricted space, causing only small affection to the surrounding work environment.

5. REFERENCES

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