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ACQUE SPA LAID 240 METERS OF DUCTILE IRON SEWAGE PIPES DN900 BY USING “HORIZONTAL DIRECTIONAL DRILLING”.

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ABSTRACT: As part of the investment plan of ACQUE SPA - the water company of the Lower Valdarno Area - for the so-called “Tubone” (the sewage collector which will convey the wastewater from the entire Valdinievole valley towards the industrial treatment plant of Santa Croce sull'Arno, for a total length of about 24 km), unprecedented work in the history of Italy’s integrated water service was carried out. It involved the laying of a long section of PAM SAINT GOBAIN ductile iron pipes using the “HDD” technique. The numbers of the intervention are remarkable: between the municipalities of Larciano and Cerreto Guidi, a portion of pipeline with a diameter of 900 millimeters was pulled, for a length of approximately 240 meters and a total weight of around 80 tons, at a depth 8 meters below street level. Pipes with special coatings and high-performance restrained joints were thus assembled in the trench. To reduce friction during traction, the trench was partially filled with water. To pull the “pipe train” through the 1350 mm diameter hole, an initial pulling force of 50 N was applied, then lowered and later maintained between 15 and 20 N. The angular deflection capability of the joints was one of the main advantages: the path was characterized by a horizontal curve radius of 800 m and a vertical curve radius of 550 m. This intervention is proposed as a "best practice" in the field of eco sustainability and circular economy, since it has combined the laying technology - with obvious advantages in terms of environmental impact compared to traditional laying – with systems in ductile iron (characterized by 100% real recyclability and no need for maintenance during operation), a perfect hydraulic seal and almost zero failure rates during the entire life cycle which exceeds 100 years.

1. INTRODUCTION

As part of Acque's work on the so-called “Tubone” (*The Big Pipe*) (the sewage collector that will convey waste water from the entire Valdinievole, Cerreto Guidi, and part of Fucecchio to the wastewater treatment plantin Santa Croce sull'Arno), an unprecedented operation took place in the history of water service in Italy. This involved the “HDD” laying of a section of pipeline. “HDD” is an acronym that stands for “Horizontal Directional Drilling”. The special feature of the work is precisely that it is possible to use ductile iron systems for pressure sewers by means of trenchless techniques even for large piping. On the border between the municipalities of Larciano and Cerreto Guidi, a 900 millimetre diameter section of the pipeline was in fact laid, for a length of approximately 240 metres and a total weight of around 50 tonnes, at a depth of about 8 metres below the road level. The ambitious project was necessary in light of the particular context in which the company commissioned by Acque for the work on Lot 2 of the “Tubone” was called upon to intervene, given the simultaneous presence of the “Francesca Nord” regional road, the two ditches perpendicular to it, and their embankments. This is where it became indispensable to apply horizontal directional drilling, instead of the more traditional “thrust boring” technology. Unlike the latter, the “HDD” technology involves drilling into the ground with the use of rods, guided by a “milling head” that prepares the path for the pipeline.

Once the “tunnel” has been created at the established depth, the pipe is hooked and pulled into the tunnel by a machine at the opposite end. This made it possible to cross the road without any impact on the road system, achieving the ideal depth and using reduced construction sites, thus also limiting the environmental impact of the operation. A new “record” has thus been set for the size of the pipeline laid and the length of the route realised. Acque S.p.A. will repeat it in the coming months, when another two crossings will be realised in Lot 4 of the “Tubone” (the section from the Pieve a Nievole wastewater treatment plant to the Uggia wastewater treatment plant, in the municipality of Monsummano Terme), again using the “HDD” technique. Another innovative element is that this type of operation is proposed as a "best practice" in the field of eco-sustainability and circular economy, since it has combined the laying technology - with obvious advantages in terms of environmental impact compared to traditional laying - with systems in ductile iron (characterised by 100% real recyclability and no need for maintenance during operation), a perfect hydraulic seal and almost zero failure rates during the entire life cycle which exceeds 100 years.

2. DESCRIPTION OF THE STEPS OF THE OPERATION

Based on the hydraulic scheme of the overall work, a main pumping station at the Pieve a Nievole wastewater treatment plant will push the waste water directly towards the final collection at Santa Croce. Along the way, three wastewater treatment plant will be converted into pumping stations connected directly to the “Tubone”. The particularity of the route is that it runs alongside Europe's largest inland wetland, the Padule di Fucecchio, which is subject to environmental protection measures, therefore, the design stage took into account the possible impacts on this sensitive area, both during the construction and the exercise phase. Main features of the project: ND900 ductile iron sewer; total length approx. 24 km; maximum flow delivered: 2,270 m^3/h; expected maximum capacity: 120,000.00 p.e.
The decision to carry out part of the work by means of Horizontal Directional Drilling (HDD) was made because of the presence of interferences along the route, in particular the crossing of a highly trafficked provincial road and the parallel position of two very close watercourses. The HDD made it possible to avoid deep excavations for any thrust pits necessary for other “NO DIG” “push” technologies and to keep due distances from interfering watercourses.

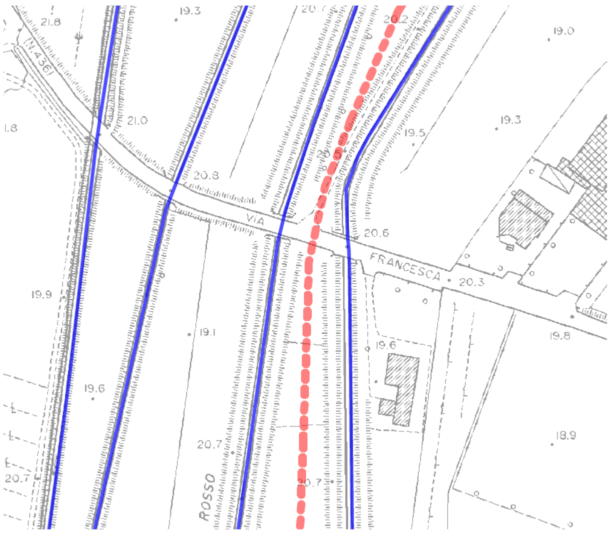

Figure 1. Layout of the pipeline with watercourses and the interfering provincial road highlighted

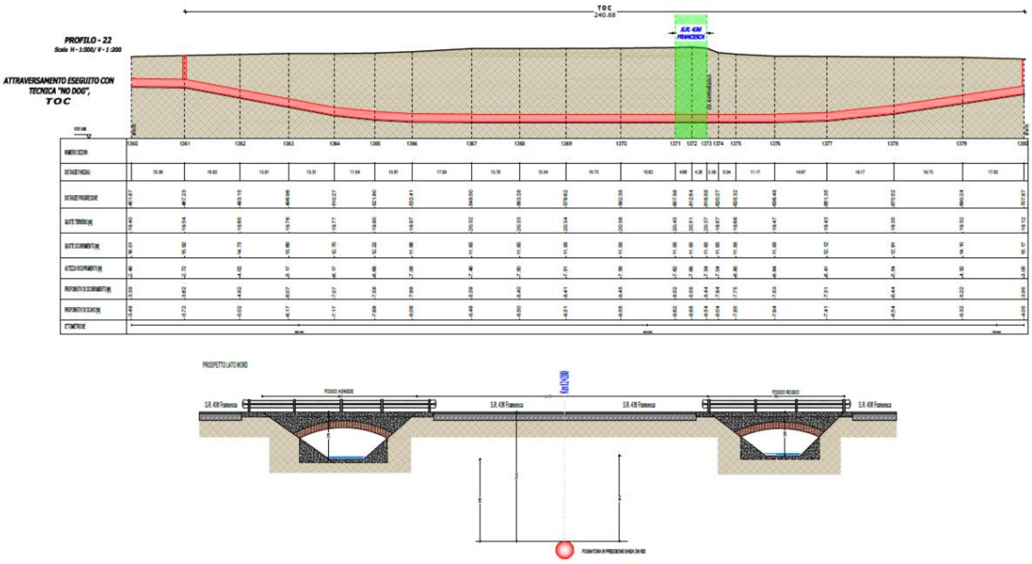

Figure 2. Profile and section of the borehole

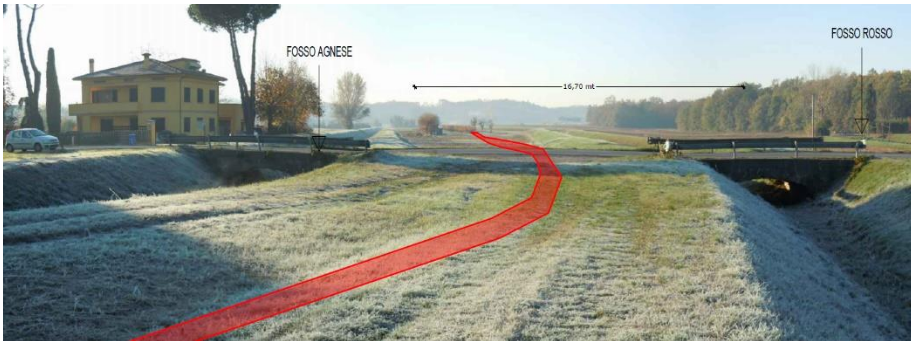

Figure 3. Representation of the pipeline route with curves in a plane section

The subsoil in the involved area is made of by clayey-loamy material. The preliminary analyses carried out during the design phase were: static electrical penetrometric tests upstream and downstream of the HDD and geoelectric investigation along the axis of the tunnel.

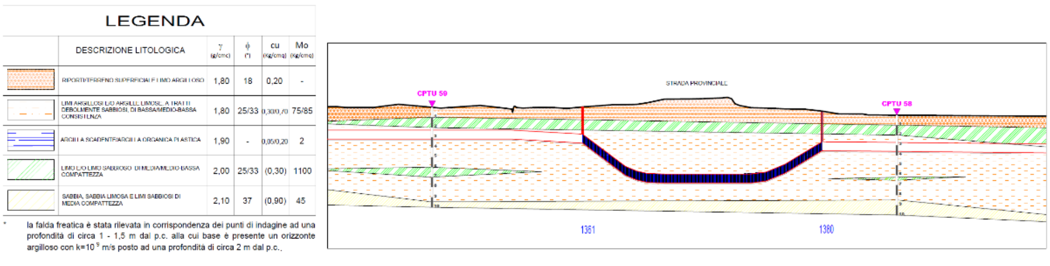

Figure 4. Geological Section - HDD Technique

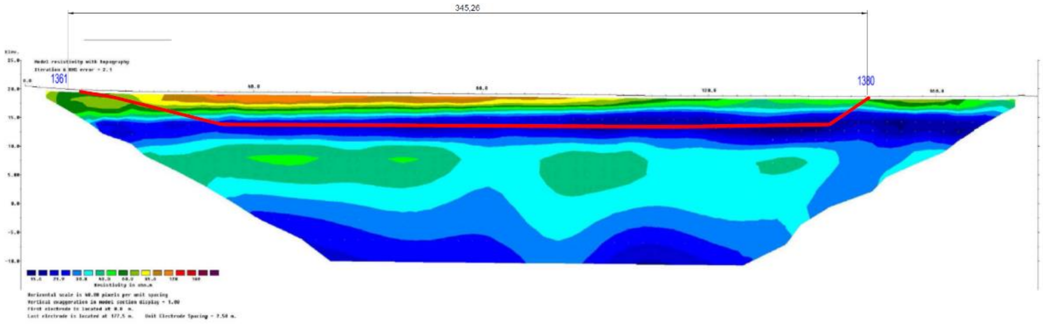

Figure 5. HDD geoelectric section

The design layout of the drilling includes a curved layout in addition to the usual height contour map. Taking into account the characteristics of the pipeline, in particular the allowed angular deviation of the restrained joints, the drilling profile was designed ensuring sufficient safety margins in the height and curved layout bending radii, assumed to be 650 m and 800 m respectively.

Characteristics of the equipment used:

- ✓ Drilling rig Vermeer D 220×500 S3:
  - Pulling force: 1,070 kN
  - Rotary maximum torque: 73,200 Nm
  - Power: 310 kW
  - Mud pump: 1,323 l/min at 83 bar
- ✓ desanding plant with hydrocyclones;
- ✓ centrifugal decanter;
- ✓ generator set;
- ✓ available excavator.

Regarding the definition of the maximum pull applied by the drilling rig when launching the pipeline, many factors are involved. The formula adopted is based on empirical data

$$F[kN] = L \cdot D \cdot f \cdot \pi$$

In the present case, f=0.5 was assumed due to the type of material. Using table data from the Drilling Contractors Association's publication "Information and Recommendations for the Planning, Construction and Documentation of HDD projects" we obtain the value of F equal to

$$F = 241{,}5 \cdot 0{,}95 \cdot 0{,}5 \cdot \pi = 360{,}2\ kN$$

Drilling and pipeline launching procedures were developed as follows:

1. Pilot drilling with 5" oil-type drill rods being 9.75 m long driven with Digitrak Falcon F5 type radio instrumentation and high-power probe.
2. Subsequent hole enlargement steps with the following diameters:
   a) 32" DN800
   b) 40" DN1000
   c) 48" DN1200
   d) 54" DN1350
   e) No. 3 bore cleaning operations with "barrel" type boring equipment DN1200
3. Preliminary assembly and testing of the pipeline before pulling and positioning it inside a flotation trench which was flooded to allow the pipeline to float during the pulling phase.
4. Once the bore was ascertained to be clean, the pipe was hooked up using the pulling head, which was specially made for this work, and the pipe was launched.

After the initial pulling effort of around 50 tons, no particular problems were encountered and the applied effort was constant from 15 to 20 tons and addition of around 500 l/min of bentonite. In about three hours, the launch was successfully completed.

Figure 6. Aerial view of the pipe train being launched with flooded trench

Given the particular type of soil, consisting of medium and low density clay, it was necessary to use high volumes of mud to loosen and transport the soils outside in order to prevent pressure from increasing in the drill channel and resulting in “frac-out” phenomena, which did occur, but were of limited extent. An average of 500 l/min of drilling fluid was added, consisting of sodium bentonite with surfactant additives, with peaks of 600 l/min.
Drilling fluids were constantly recycled thanks to the installation of a desanding plant with 4" hydrocyclones and a centrifugal decanter, which allowed the separation of the finer component of the spoil, resulting in a reduction of the total volume of mud produced.
The drilling mud was recirculated either by pumping between the launch pit and the machine-side pit or by tanker transport.

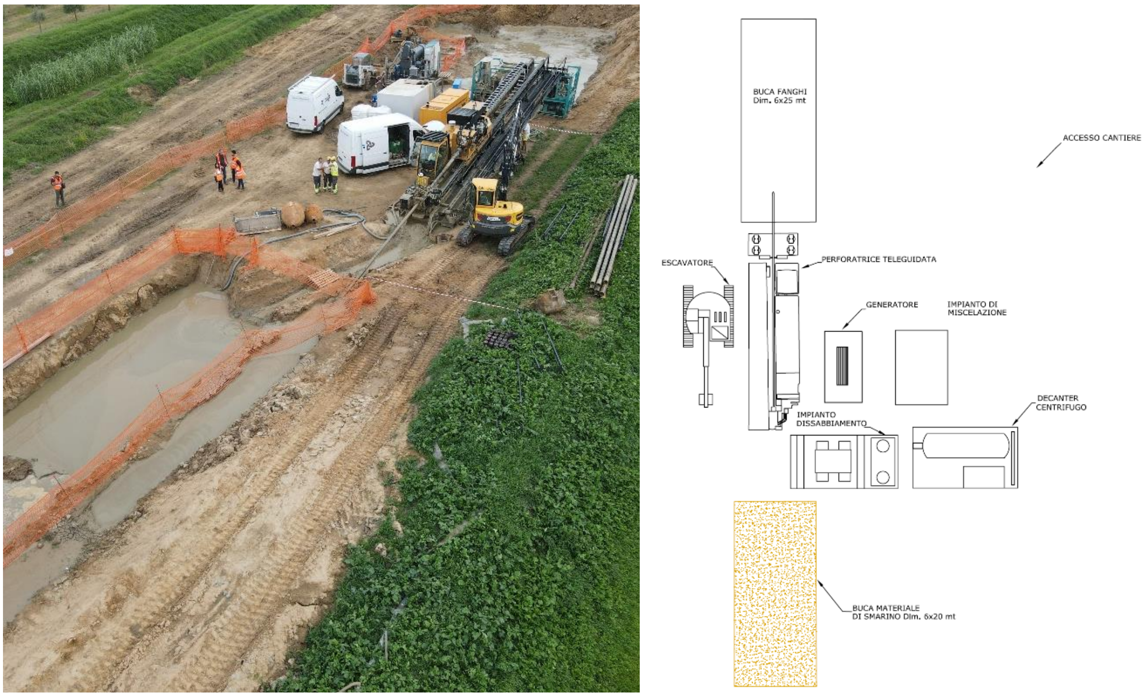

Figure 7. View of the site from the side where the drilling machine was positioned

Table 1. Drilling fluid volume

		Diameter	Generated solid volume	mud factor	cutting	Mud volume required	Mud volume required	ROP	Theoretical flow rate	Lost factor circulation	Pump flow rate
		[mm]	[m³]		[%]	[m³]	[m³×m]	[m/min]	[l×min]		[l×min]
Pilot hole	D	250	13.9	6	16.6	83.4	0.29	1.21	500	1.4	357
boring	D1	609	68.5	6	16.6	411	1.45	0.29	500	1.2	417
boring	D2	813	64.5	5	20	322.5	1.14	0.59	800	1.2	667
boring	D3	1,016	82.5	3	25	247.5	0.87	0.88	850	1.1	773
boring	D4	1,219	100.8	3	33	302.4	1.07	0.72	850	1.1	773
boring	D5	1,371	87.5	3	33	262.5	0.93	0.93	950	1.1	864
cleaning	D4	1,219	0			240	0	1	850	1	850
launch	D	1,219	0			35	0	4	500	1	500
total			417.7			1,904.3	0.37				
DP rods 4" 1/2 IF L 9.75											
Bentonite - total with recycling [m³]						1,904.3					

3. DESCRIPTION OF THE DUCTILE IRON PIPES USED

The Saint-Gobain PAM ductile iron pipes used, which are specifically for installation by HDD, are of the TT PUX type, namely with an external coating made of an adherent layer of reinforced polyurethane applied by projection on the surface of the pipe in accordance with standards EN 598 and EN 15189. The jointing system is of the UNIVERSAL STANDARD VE automatic elastic restrained type with pipe angular deflections and longitudinal shifts while the hydraulic seal is kept uninvolved. It is equipped with a double chamber socket made from a single casting: the inner chamber houses the gasket with dovetail profile according to UNI 9163 in NBR, in compliance with standard EN 681-1, which ensures the hydraulic seal, while the outer chamber houses the ring which ensures resistance against slipping thanks to the weld seam on the smooth end of the pipe.

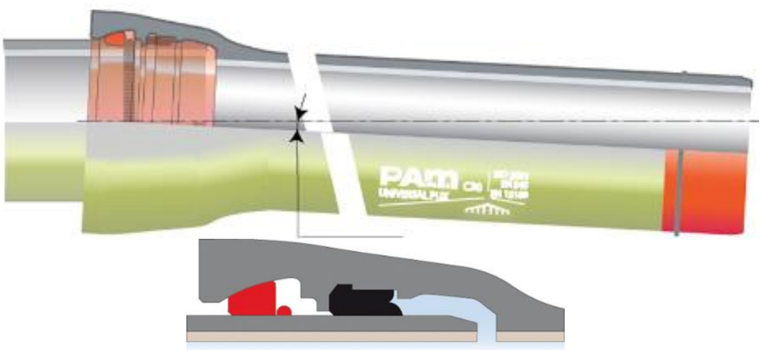

Figure 8. Type of joint used

The elastic joint, which it is known to allow cast iron being laid in soils characterised by differential settlements with no modification to the pipe tensional state (such settlement events are absorbed by the angular deflection allowed by the joint), in the case of laying by HDD allows for the considerable bend radius values shown in figure 9.

Angular deflection and curve radius

DN	Joint	Angular deflection	PFA (bar)	Allowable curve radius (m)
100	Uni Ve	3°	64	115
150	Uni Ve	3°	55	115
200	Uni Ve	3°	50	115
250	Uni Ve	3°	45	115
300	Uni Ve	3°	40	115
350	Uni Ve	3°	38	115
400	Uni Ve	3°	35	115
450	Uni Ve	3°	32	115
500	Uni Ve	3°	30	115
600	Uni Ve	2°	27	172
700	Uni Ve	2°	25	172
800	Uni Ve	2°	25	364
900	Uni Ve	1.5°	25	445
1000	Uni Ve	1.2°	25	572

Figure 9. Angular deflection and allowed bending radius of the Saint-Gobain PAM pipes used

The joint has been designed to withstand the high maximum allowed tensile stresses that characterise HDD laying. Figure 10 shows the maximum allowed pulling forces defined based on the maximum acceptable pressures of Saint-Gobain PAM's UNIVERSAL STANDARD Ve® restrained joints. The system also makes it possible to pre-test the pipe before it is pulled into the hole.

Allowable pulling forces (kN)

	Pulling lengths (km)					
DN	0 to 0,4	0.5	0.7	0.9	1	1.2
100	87	84	77	70	66	59
125	114	109	100	91	87	78
150	136	131	120	109	104	93
200	201	193	177	161	153	137
250	271	260	239	217	206	184
300	342	329	301	274	260	233
350	426	409	375	341	324	290
400	506	486	445	405	384	344
450	579	556	510	463	440	394
500	667	640	587	533	507	453
600	855	821	752	684	650	581
700	1000	961	881	801	761	681
800*	1225	1177	1078	981	932	834
900*	1473	1415	1297	1179	1120	1002
1000*	1725	1657	1519	1381	1312	1174

Figure 10. Allowed tensile forces of the Saint-Gobain PAM pipes used

All joints are equipped with a heat-shrinkable sleeve and a metal cap that ensure protection of the socket, especially in the event of accidental creep during pulling.

In order to reduce the tensile strength of the pre-assembled pipe train, a flooded trench as shown in Figure 6 was provided instead of a roller routing system due to the presence of a deviation in the planimetry layout. Furthermore, the hydrostatic buoyancy exerted by the bentonite inside the borehole required a ballasting of the pipe train, which in this case was achieved by directly filling the pipe with water.

4. CONCLUSIONS

This work of laying of DN900 ductile iron pipeline using the Horizontal Directional Drilling (HDD) technique, which set a record for the largest DN ever laid with this technique and this material, represents a worldwide case history made possible by the combination of far-sighted and courageous design by the Network Owner, professionalism in laying by the assigned company, and the quality of the pipes used. All this has resulted in a truly eco-sustainable project, both because of the trenchless non-invasive laying technique and the use of a material - the ductile iron of the chosen pipes - which, according to countless empirical references, ensures an expected service life of more than 100 years. Therefore, this can be defined a low environmental impacting work, to be benefited by several future generations.