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THE CHOICE OF THE BEST TECHNOLOGY FOR LAYING AN UNDERGROUND PIPE. A SUCCESSFUL CASE: CROSSING THE ADDA RIVER WITH THE DIRECT PIPE METHOD

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ABSTRACT: The continuous development of trenchless technologies offers today the possibility to identify and use different alternative no-dig systems for the same project. International and national standards clearly describe and classify all available trenchless technologies and their typical application range. Nevertheless, a specific investigation and risk assessment are necessary to choose the proper design according to the Client's needs. Recently, I.CO.P. S.p.A. completed the Adda river crossing in a very complex geological situation where HDD had been previously applied without success. After execution of additional geological investigation, and after a proper risk assessment, Microtunnelling and Direct Pipe were identified as possible solutions. The final choice was to install a big casing pipe (56") with the Direct Pipe system. Based on the experience gained in the last years in Direct Pipe works, it was decided to design a dedicated cutting head and deploy tailored operating procedures which allowed to successfully complete the work. In the present paper we describe how it was possible to execute the Adda river crossing using Direct Pipe. It has been demonstrated that an important step forward has been done to enlarge more and more the applicability of the Direct Pipe system.

1. INTRODUCTION

In ancient times, the construction of hydraulic works, such as sewers and aqueducts, allowed the creation of urban agglomerations, where many people could live in very restricted areas, in acceptable or even good hygienic and sanitary conditions.
These infrastructures were considered so important that many of them were real masterpieces, and are still remembered with the name of the lords who ordered and financed their construction.
Among all, the ancient Romans certainly distinguished themselves in these activities, with many works of considerable archaeological, historical and cultural value even today, which are sometimes still working.

Figure 1. Rome - Aqueduct Park

Figure 2. Rome - Cloaca Maxima

The production of medium/large diameter pipes, made possible over the years thanks to the development of specific technologies, considerably simplified the construction of hydraulic infrastructures, both in urban and extra-urban areas. This has allowed to improve the usability of services, meeting the widespread and ever-increasing needs and promoting environmental awareness.
Despite the clear advantages of using pipes produced on an industrial scale, which limits the construction of massive works (manholes, inspection chambers, siphons, collection systems, etc.) to a few end points, their installation has an important impact all along the pipeline length, whatever its function.
Technology has taken remarkable steps forward minimizing the problems associated with pipe laying. Different techniques, even highly advanced, are available. Operators can choose the most appropriate one according to specific qualitative and environmental parameters, as well as depending on vehicular traffic and city management.
The development of construction technologies and pipe laying techniques together with the transformation of the cities and the increasing environmental awareness over time, changed the approach to hydraulic works from wanting to highlight and almost celebrate the presence of great hydraulic works, to trying to make them "invisible", both in the construction and use phases.

2. OPEN TRENCH EXCAVATION OR NO-DIG TECHNOLOGIES

2.1. Open trench excavation

Underground pipe laying has been for a long time made by digging open trench excavations up to the pipe laying level and subsequently backfilling the same.
This method of installation requires taking into account several factors at design stage, such as:

- The accessibility of the areas, and therefore the adaptation of the pipeline route;
- The depth of excavation;
- The methods for supporting the excavation walls;
- Traffic management, in case of interference with existing roads;
- Water management in case of river crossing;
- The restoration of pre-existing surface conditions, especially when crossing roads and infrastructures, and the restoration of pre-existing naturalistic and environmental characteristics, especially considering the increasing environmental awareness;
- The need to manage large volumes of excavation, in compliance with environmental management regulations and laws.

2.2. Pipelines laying with NO-DIG technologies

The ever-increasing problems connected to the installation of underground pipelines in urban areas and in areas of high environmental value have given an impetus to the development of technologies allowing to overcome or even eliminate such difficulties. Technologies that contributed and contribute the most to effectively solving these issues are called "NO-DIG" or Trenchless Technologies.
These techniques, developed since the end of the Second World War, also due to the need to restore hydraulic systems in heavily devastated cities like Berlin and Tokyo, have gradually evolved resulting in different intervention approaches. For example, the HDD technique is based on drilling a small diameter pilot hole and then reaming the hole until it has a diameter suitable for the pipe to be inserted, while Pipe Jacking is based on the concept of jacking pipe segments from a launch shaft to a reception shaft where the cutterhead is recovered. Pipe Jacking then evolved into Microtunnelling, which allows higher performances and significantly greater drive lengths. Many trenchless technologies have been developed over time. Each technology has specific features; therefore, a ranking is not possible. Some basic parameters shall be evaluated for each situation, which may lead to the choice of a NO-DIG technology rather than another one.

2.3 Criteria for the selection of NO-DIG technologies

Basic parameters defining the characteristics, and therefore the feasibility, of a pipeline work, are:

- The pipeline length;
- The characteristics of the pipe to be installed;
- The outer diameter of the pipe;
- The geological and geotechnical characteristics of soils to be crossed;
- The hydrological characteristics of soils to be crossed;
- The planimetric and altimetric profile of the pipeline to be installed;
- The precision required in order to use the work;
- The execution timetable;
- The accessibility of the areas;
- The traffic conditions of access routes;
- The available budget;
- The execution risk.

Once the project characteristics are identified, it is possible to choose the most suitable technology among the existing ones to execute the works.

2.4 Reference laws and regulations for the selection of NO-DIG technologies

As already pointed out, different NO-DIG technologies have been progressively developed, sometimes in order to solve different problems, sometimes aiming at solving the same problem, giving the designers and the commissioning companies the possibility to choose among different technological solutions according to their experience and attitude.

The designers and the client companies need appropriate regulatory instruments that can help them in choosing among the different possible solutions, in search for objective elements that could support them in making the most appropriate choice.

The German standards **DWA-A 125-2008 Pipe Jacking and Related Techniques**, providing a catalogue of different techniques and corresponding technical features, have often been taken as a main reference.

Recently, upon proposal of the IATT (Italian Association for Trenchless Technology), the UNI (Ente Italiano di Normazione) has published the following reference procedures:

- **PdR 26.03:2017 – Technology for the construction of low environmental impact, underground infrastructures. Guided drilling systems: Horizontal Directional Drilling (HDD);**
- **PdR 26.02:2017 –Technology for the construction of low environmental impact, underground infrastructures. Installation of jacked pipes by means of horizontal drilling.**

These regulatory documents, in addition to defining some technologies by specifying the main differences between them, propose the main NO-DIG technologies currently available for laying a pipeline.

In particular, while the PdR 26.03: 2017 procedure defines and regulates only the Horizontal Directional Drilling technology and its aspects, the PdR 26.02: 2017 procedure defines and regulates the following technologies: pneumatic drilling machine; thrust boring machine; auger boring machine; down-the-hole hammer drill; open shield TBM; closed shield TBM; microtunnelling; pilot system; Direct Pipe.

For these technologies, some tables of comparison are reported to allow a first feasibility study and selection of a project according to boundary conditions and reference parameters.

This is certainly not enough to choose a technology, but it will allow focusing on the technologies that may be theoretically suitable for the project, thus significantly reducing the possible margins of error.

3. CASE HISTORY: ADDA RIVER CROSSING WITH THE DIRECT PIPE METHOD

3.1 Introduction

In the field of NO-DIG technologies, sometimes different techniques can be used providing different possible solutions that may be approached progressively depending on the actual condition of the sites and type of soil.

The present case history deals with the crossing of the Adda River, between the Municipalities of Vaprio d'Adda (province of Milan) – launch side – and Canonica d'Adda (province of Bergamo) – reception side.

The works are part of the Snam Rete Gas project named «Potenziamento della rete di Vaprio D'Adda», which involves the installation of a new DN 200 (8") pipeline for an overall length of 8 km in order to expand and dismiss the existing gas pipeline. The existing pipeline was secured to the Canonica d'Adda bridge structure. In order to limit any potential risk and minimize impacts, Snam Rete Gas has envisaged to use NO-DIG techniques for the new Adda river crossing project.

3.2 First Approaches: HDD

The first design developed by the Client envisaged the use of the HDD method, which appeared to be the one that could give the best results from a technical and economical point of view.

Even if a geological investigation as detailed as practicable had been carried out at the preliminary stage, the soil conditions encountered along the drilling profile made it extremely difficult to execute the pilot hole, which is an essential step of the HDD method, prior to proceeding to the following pre-reaming stage. In fact, the pilot hole had to be excavated in a very heterogeneous situation, which consisted of an alternance of coarse loose soils with boulders and of hard conglomerate from the "ceppo dell'Adda" formation. In the end, it was not possible to successfully complete the installation by HDD.

3.3 Final Choice: Direct Pipe

Due to the problems highlighted above, the Client – after investigating possible alternative technologies (i.e. microtunnelling and direct pipe) – chose the Direct Pipe method, one of the most recent techniques within the family of NO-DIG technologies.

The most important challenge in the execution of the crossing consisted in selecting the design of the cutterhead and the drilling parameters which were better suited to perform in a continuously changing and very complex geological condition, consisting of loose coarse gravel and of the "ceppo dell'Adda" formation; in addition, the high groundwater level and the high permeability imposed to build the launch pit almost at natural ground level.

Considering that this technology could not by applied to directly install the product pipe due to its small diameter (8”), a suitable casing pipe was selected between 48” and 56”. Based on previous experiences and risk assessment, the decision was to install a 56” casing pipe.

Figure 3. View of Direct Pipe launch and reception pit area

4. DESCRIPTION OF THE PROJECT

The Direct Pipe crossing method consists in crossing the Adda river starting from a launch pit located on the right bank in the municipality of Vaprio d'Adda (MI) and a reception pit on the left bank in the municipality of Canonica d'Adda (BG), for an overall length of 426.34 m. The pipe diameter is 1400 mm (56”), 21.2 mm thickness, with a polyurethane coating. Two 8” pipes were then inserted inside the Direct Pipe, one of which is connected to the gas pipeline, whereas the second one is a duct for ancillary services. At the end of the works, the gap between the two 8” pipes and the 56” pipe was grouted with a cement-bentonite mixture.

Table 1. Main crossing data

Direct Pipe	TBM	Control Cabin	Thruster	Length [m]	ND [mm]	Straight section / Gradient	Curved sections
Adda River crossing	AVN1200TC	M1427C	HK750	426.34	1400 (56”)	98,37m; -7,00%	Vert.Curve L=327,97; R = 1600m

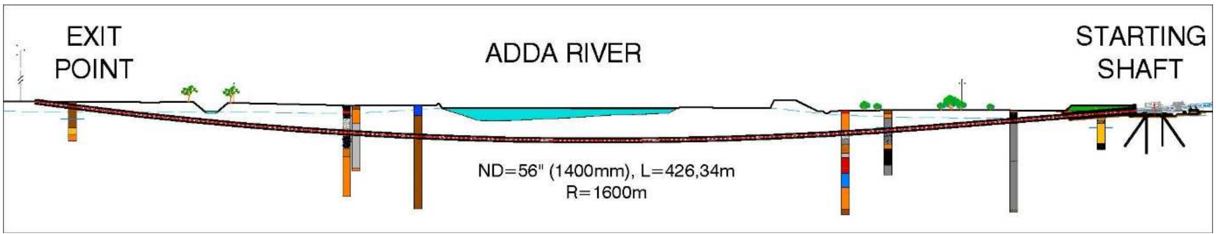

Figure 4. Adda River Direct Pipe crossing: Plan and Profile (deformed)

4.1 Geological Data

The launch pit is located inside the Adda River Park, in an area previously used as an alluvial retention basin, while the reception pit is on the left hydrographic bank in the municipality of Canonica d'Adda.
A total of 8 boreholes, 4 at the thruster side and 4 at the reception side were made along the “Adda River” crossing. Preliminary surveys have shown that geology at launch pit side is characterized by alluvial deposits with the presence of coarse gravels, coarse sands and possible presence of boulders.
The presence of a more or less cemented “ceppo dell’Adda” formation was also found, i.e. a geological formation generated by lithic Pleistocene fluvial deposits. This formation consists of sandstones and conglomerates composed of rounded clasts of different sizes from centimeters to decimeters, with arenaceous matrix and a variable degree of cementation.
As it was not possible to investigate subsoil conditions under the river bed, a certain level of uncertainty was still remaining in this section of the drive. Towards the exit section, the investigations have shown less inhomogeneity of soils with the presence of sandy layers and gravel portions.

Table 2. Geologies crossed

Geologies crossed	
Chainage [m]	**Soil crossed**
0 -80	Coarse gravel, pebbles
80 – 95	Coarse gravel, pebbles, boulders
95 – 135	Coarse gravel, pebbles, coarse sand
135 – 140	Cemented section
140 – 210	Coarse gravel, pebbles
210 – 245	Coarse gravel, pebbles, coarse sand
245 – 330	Coarse gravel, pebbles
330 – 370	Coarse gravel, pebbles, coarse sand
370 – 405	Coarse gravel, pebbles

Given the punctual information given by boreholes, the high inhomogeneity and variability of the expected lithotypes, it was not possible to reconstruct a reliable geo-mechanical profile showing the changes in lithology, the density discontinuities and the position of the cemented layers during drilling operations. Drilling operations confirmed project data, with some local changes.

The excavation of the Direct Pipe showed the following situations: initially layers of particularly loose soil mainly composed of coarse gravel and pebbles, layers with the presence of boulders and cemented layers/ceppo dell'Adda. Layers with coarse sand together with gravel were found in the river bed and at Direct Pipe reception side bank.

Figure 5. Material coming out of the separation plant

4.2 Engineering and Design

Construction site layout was designed basing on the areas the Contractor made available.

Figure 6. Top view of construction site area

Preliminary activities for the preparation of the area, including vegetable topsoil removal, levelling and backfill of stabilized material, were carried out by the main contractor, over an area of approximately 5000 m2. To cross the irrigation channel passing through the construction site, reinforced concrete box culverts have been installed to allow the transit of the vehicles and the positioning of the rollers on the launch side.

4.2.1 Launch Pit

The launch pit shall accommodate the advance/thrust unit ("Pipe Thruster", PT) and allow its full operation in safe conditions. The launch pit consists of a slab and a wall, both in reinforced concrete, adequately sized to withstand all external stresses: actions exerted by the Pipe Thruster and possible overloads at the ground level.

In order to transmit the vertical actions exerted by the Direct Pipe machine on the slab to the underlying ground, a series of reinforced concrete micropiles, having a diameter of 25 cm and lengths between 12 and 15 m, were installed at the anchoring points of the Pipe Thruster to the slab.

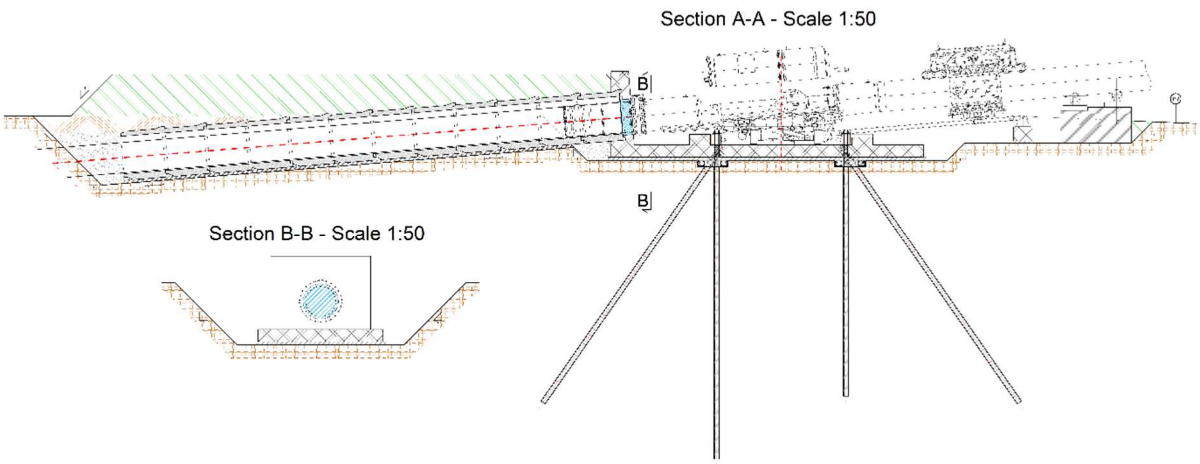

Figure 7. Launch pit design drawing

The vertical connection of the Direct Pipe machine to the piles is ensured by positioning n.4*4 Dywidag threadbars, embedded in the slab casting, in correspondence with each counterfort.
The horizontal actions exerted by the Pipe Thruster are transmitted to the slab, which is provided with two 6m long and 1m wide reinforced concrete connection ribs extending in an orthogonal direction as regards the thrust direction, and between which the PT base frame is positioned.
Due to geology, gravel and loose sand, and surface water level, the launch pit level line was fixed at a depth of about 1.5 m from the ground level. As the TBM entry point was located at a quite shallow depth, a 24 m long casing pipe consisting of 12 precast concrete segments (DN 1800 mm) was built behind the entry wall.
The construction of the casing pipe was necessary in order to guide the TBM in the first section, ensuring an adequate coverage at the beginning of the drilling, minimizing slurry releases and leakages on the ground.

Figure 8. Top view of the entry casing pipe

4.2.2 Launch way

The overall length of the Direct Pipe was 426.34 m. Due to the storage space available at the launch side, 2 pipe strings of approximately 215 m were prepared and then pushed. The launch way for the pipe strings was prepared by installing the rollers on 16 concrete pillars which were casted in place at a distance of approx.15 m. The launch way height ranged between 2.2 m and 0.97m above the ground level.
The second string was prepared and welded parallel to the first one. When the first string was jacked, two mobile cranes with a lifting capacity of 150 tons, 1 crawler crane with a lifting capacity of 40 tons and 2 side-booms of 90 tons were used to move the second string on the rollers in order to weld it to the first string.

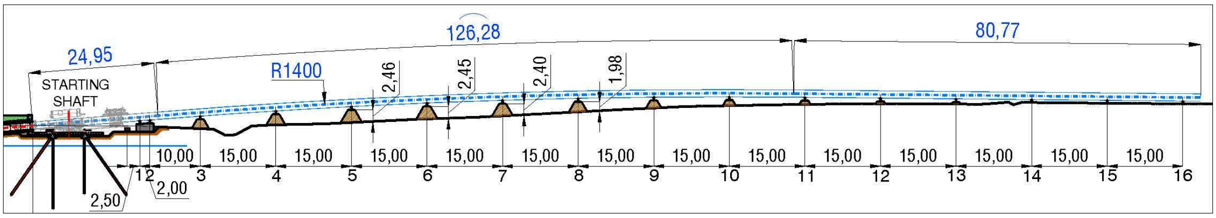

Figure 9. Overbend design drawing

Figure 10. Top view of pipe strings

Figure 11. First string welded and laid on rollers

4.3 Equipment

A Herrenknecht **AVN1200TC** TBM with an OD 1500 mm, specifically arranged for DP applications, composed of 5 interconnected elements was used. The joints between the elements allow the transfer of both thrust and pulling forces, while making at the same time the jack guidance system effective thanks to their vertical and horizontal flexibility. The TBM consists of the following elements:

1. (AVN1200TC) TBM drilling shield and cutter head - a rock cutter head was used;
2. head control unit;
3. telescopic station control unit;
4. telescopic station;
5. conical connection element - it is a transition element whose larger diameter side connects to the telescopic station, while the smaller diameter side connects to the pipeline; the bentonite lubrication line for the overcut is also placed in this section.

Figure 12. Top view of the TBM assembled and ready for launch operations

Figure 13. TBM installed on the Thruster

Figure 14. TBM rock cutter head

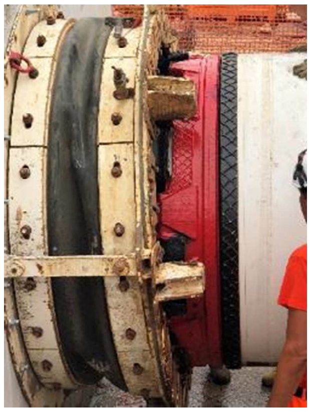

Figure 15. TBM inserted in the launch seal

The **Pipe Thruster (PT)** transfers, by friction, thrust and pull forces on the pipe by means of clamps, acting through single 5 m strokes. In case of obstacles in the ground, the PT can also be used to pull back the pipeline. The clamping system consists of three rings each one equipped with 4 clamping plates coated with vulcanized rubber in order to prevent damages to product pipe coating.
For this project, a PT type HK750PT was used, the most powerful currently available, having the following technical features:

Pipe Thruster: driven by hydraulic cylinders
Vertical inclination angle: 0°-15°
Diameter range: 48”- 60”
Advance force: 7.500kN
Pull force: 7.500kN
Max. advance rate: 3m/min
Max. cylinder stroke: 5000 mm

Figure 16. Pipe Thruster installed in the launch pit

Figure 17. Pipe Thruster in operation

All drilling activities were managed by the TBM operator from the **control cabin**. From the control panel, the operator has access to all the required information concerning the TBM and the Pipe Thruster, i.e.:

- Delivery and return slurry circuit flow rates and corresponding operational parameters of the slurry circuit pumps
- Jacking pressure
- Pressures at the excavation face
- Cutting head rotation speed

- Advance rates
- Bentonite lubrication system
- Guidance system

The TBM is “guided” from the control panel through an integrated position and control system. This system consists of level sensors for determining the altitude, a gyroscope system for determining the horizontal angle and a chainage measurement wheel. Based on the data measured by these three systems, the computer is able to continuously calculate the position of the TBM. Consequently, based on the data provided by the control system, the guidance system allows to correct the position of the TBM acting individually on the steering cylinders with the same concept as in the Microtunnelling.

A suitable lubricating layer shall be present in order to reduce frictional forces between the ground and the pipe. Such layer is created by filling with bentonite fluid the overcut, i.e. the gap between the pipeline (1422mm) and the borehole (1505mm) excavated by the TBM.
Unlike the Microtunnelling technique, where the lubrication takes place by injecting bentonite through nozzles arranged in the reinforced concrete jacking pipes, in the DP method, since the product pipe cannot be drilled, lubrication takes place: at the first machine can, at the conical element and at the launch seal.

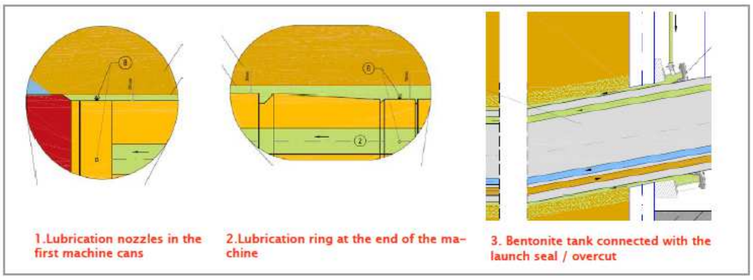

Figure 18. Bentonite injection points on the TBM and on the launch seal

Due to geological conditions – presence of coarse and loose gravels – the overcut lubrication was particularly important in order to maintain the thrust forces within the equipment permissible limits.
The bentonite was prepared in a MATT SCK 14-25 mixer and transported to the injection points by means of 2 Obermann DP 101 injectors.

Similarly to the Microtunnelling technique, the excavation takes place using a drilling fluid. In this specific case, water and bentonite were used to ensure a suitable viscosity of the excavation fluid in order to transport gravels out of the pipeline and avoid its deposit along the slurry lines.
The excavation fluid is delivered to the machine head by means of a delivery pump. The excavated material suspended in the fluid is pumped out to the separation plant through a return pump, where the solid fraction is separated from the liquid. The latter is recirculated in the slurry circuit, while the solid fraction is stored in a specific area for subsequent disposal.
For this project, a Bauer BE 425 separation plant was used, consisting of a primary separation screen, 2 stages of secondary separation screens, two 18-inch cyclones and a desilter with six 6” cyclones.
The separation plant was completed by a centrifuge and a Herrenknecht flocculation system.

Figure 19. Separation plant

Figure 20. TBM exit

4.4 Some Data

The entire project duration was 90 days, starting from the preparation of construction site areas, to the execution of the Direct Pipe drilling and completion of grouting after product pipe pull-in. Despite all the criticalities, the crossing was completed in compliance with the contractual schedule.
The average drilling production was 18.5 m/day with a peak of 33 m/day in a single shift.
During the drilling phases, the maximum thrust force recorded by the Thruster was 620 tons, with an average thrust force of 420 tons

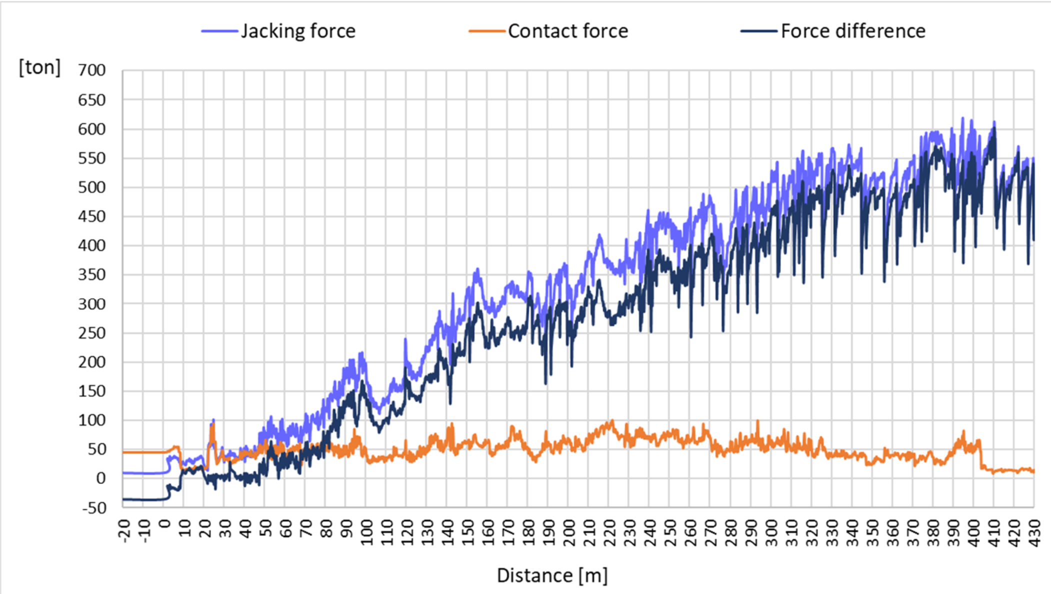

Figure 21. Jacking and Contact Forces

4.5 Involved Companies

Client:	SNAM Rete Gas – Milano (MI) - Italy
Main Contractor:	Pizio S.p.A. – Dalmine (BG) - Italy
Direct Pipe specialized subcontractor:	I.CO.P. S.p.A. – Basiliano (UD)- Italy

6. CONCLUSIONS

NO-DIG technologies are constantly evolving, also due to the increasing need to reduce the impact on the environment and urban areas.
There are more and more technologies, even regulatory instruments, helping the users to choose every time the most appropriate NO-DIG technology to be used.
After unsuccessful attempts with the HDD technique, the crossing the Adda River using the Direct Pipe method represented a successful challenge for all the parties involved in the project.
Different critical issues emerged since the planning of crossing works:

- geological conditions at the limit for small/medium diameter trenchless technologies due to the presence of coarse gravels and cemented layers;
- logistics, due to the only access road to the site with weight restrictions and placed between the Adda River and a towpath;
- execution times; the delay in beginning the activities has led to hurry up execution times as much as technically possible.

However, criticalities and difficulties did not prevent the completion of works, which were achieved ensuring high levels of quality, personnel safety and respect for the environment.

6. REFERENCES

DWA-A 125-2008 Pipe Jacking and Related Techniques

PdR 26.02:2017 –Technology for the construction of low environmental impact, underground infrastructures. Installation of jacked pipes by means of horizontal drilling

PdR 26.03:2017 – Technology for the construction of low environmental impact, underground infrastructures. Guided drilling systems: Horizontal Directional Drilling (HDD)