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A MICROTUNNEL WITH A VERY LITTLE RADIUS FOR A BIG PIPELINE

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ABSTRACT: The use of the curvilinear microtunnel in c.a., for the installation of large diameter pipelines carrying natural gas, is now a well-established practice to overcome watercourses or major infrastructures. The choice to build a microtunnel with a curvilinear profile allows to significantly reducing the depth of pushing wells and the receipt of drilling and, consequently, the risks associated with underground work.

The mechanical characteristics of the steel pipe to be positioned in the microtunnel heavily affect its size as the elastic radius of the pipe determines the minimum radius of the curvature of the microtunnel. In the case in question, a ND 1400 (56 ") steel pipe with a usual bending radius of about 1.600 m was laid to cross the Highway “Autostrada del Sole” by means of a microtunnel with an internal diameter of 2.100 mm.
For the first time in the microtunnel, which we call "Costa Rica", of only 156 m length, it was possible to lay the pipeline with a radius of curvature reduced to only 800 m, much lower than that normally used. This was possible thanks to an innovative design choice that entrusted the success of the work to the perfect execution of the microtunnel along the project profile and the ability of the workers responsible for assembling the pipeline to manage it with absolute skill. The construction of the entire work, including the laying of the pipeline, was carried out in a shorter time and with absolute precision.

1. INTRODUCTION

To cross the highway A1 near the tollbooth at Melegnano, we chose the technique of the microtunnel for the installation of a steel gas pipeline DN 1400 (56 "), 75 bar of working pressure. Using these method two operational solutions were possible.
The first consisted in building a straight microtunnel, of limited length, about 120 m, which necessarily implied the construction of deep jacking and receiving shafts to ensure the planned depth of about seven meters below the highway.
The second involved the construction of a curved microtunnel with a radius of curvature of 2,000 meters, for a total length of approximately 260 meters. The latter option allowed constructing a jacking shaft of limited depth and, at the same time, to avoid the receiving shaft by predicting the final point of drilling on the laying of the pipeline.
Both the solutions involved positive and negative aspects and this led us to find a third solution, never tried out before, which would combine the most favorable aspects of the two hypotheses mentioned above.
This innovative solution, analyzed and implemented, allowed us to keep the overall length of the crossing within just 156 meters, to create a not very deep pushing station and to avoid the construction of a receiving station (see Figure 1).
This was possible only through the previous cold curving of all the steel pipes DN 1400 (56") to be installed in the microtunnel, imposing in the project a radius of curvature of only 800 meters. **The above operational procedure was applied for the first time ever.**

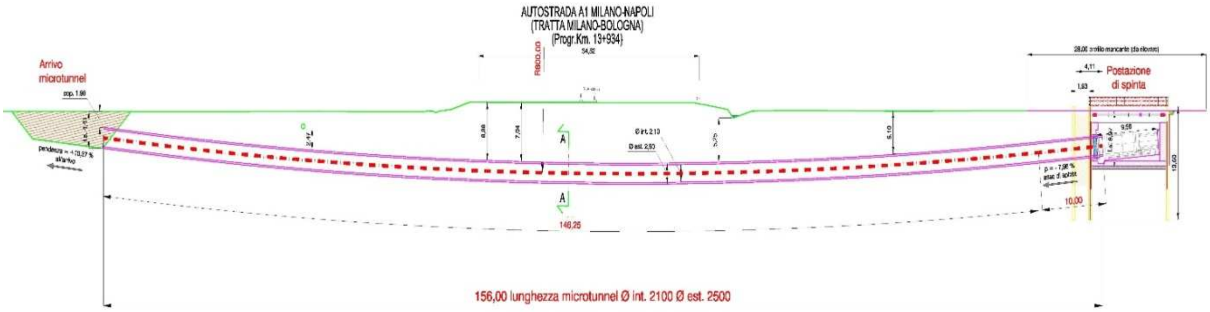

Figure 1. Project profile of the Microtunnel

All the pipes, made of approximately 14.5 m long bars, were consequently bent by one degree to ensure the bend radius we imposed during the project phase, instead of the elastic radius of the pipe.
Below The main stages of the work we developed and implemented are described below.

2. CIVIL WORKS

Morphological considerations

The crossing is located in an almost flat area, for agricultural use, east of the town of San Zenone al Lambro (see Figure 2, satellite view of the area). The access from the Provincial Road 204 was possible thanks to a dirt road used for agricultural purposes, duly reinforced to allow the traffic of heavy vehicles and properly restored at the end of the construction activities...

Figure 2. Aerial view of the Highway A1

Geological-geotechnical considerations

Our considerations were based on the geological-geotechnical report prepared by the contractor. In March 2012 n° 1 geotechnical survey through drilling was carried out at the crossing of the "highway A1", at about 65 m from the shaft (S17 – depth 15 m), complete with progress tests performed at various depths (S.P.T. Tests) and with the taking of samples (C.R.) for laboratory analysis. The stratigraphic succession is represented by alternating lithotypes which can be referred to the medium and old Alluvium and to the Fluvial Würm". The lithological types along the profile drilled by Microtunnelling technique are made by a certain lithological variability, with frequent alternation of medium-fine silty sands, not very stiff silty clays and silts with fine sands. That is valid up to a depth varying from -9 to-15 m compared to the c.p. (countryside plan) below the surface. The groundwater level was found between -4.5 and -5.3 meters deep.

Main technical data civil activities

The following are the main technical data of the crossing:

- Overall length: 156.25 m
- Internal diameter concrete pipe: 2,100 mm
- Inner diameter reinforced concrete blocks: 2,500 mm
- Profile of perforation: curvilinear
- Radius of curvature applied: 800 m
- Jacking shaft: with sheet pile and foundation plate and walls in reinforced concrete.
- Hydraulic flap elevation: -4.5 m
- Soil: Sands, silts and clays

Realization of the microtunnel

The perfect realization of the microtunnel was essential for the following laying of the steel pipe forming the gas pipeline in order to avoid imbalances during the installation of the line.

After all the preparatory activities including the realization of the site area, of the pushing station and the placement of the cutter, the drilling was carried out.

On November 20th, 2017 the Herrenknecht AVN2000 - manufactured TBM was installed in the trap and positioned on the pushing track, equipped with a milling shield for mixed terrain.

Once the hydraulic and electrical connections were completed and the tests done to verify the correct operation of the mechanical and electronic parts of the TBM and the correct communication of this with the control cabin, the guiding system was installed. Since this is a tunnel characterized by a vertical curve, it was necessary to mount a VMT model SLS guide system that would allow the trajectory control along a curved path. This type of guiding system, together with the Herrenknecht control cabin, allows the continuous control of multiple excavation parameters, including the position of the cutting head, the roll angle and its inclination to the horizontal, the pressures acting on the pushing jacks and the hydrostatic and contact pressures acting on the TBM head; in addition, it is possible to monitor the flow rates and pressures of the sludge evacuation system.

On November 23rd, 2017, once the installations necessary for the start-up were completed, the TBM started drilling the header wall. A seal ring was mounted upstream of the wall to prevent the flow of fluids into the trap. The drilling ended at a progression of approximately 165 m on December 6th, 2017. The greater length of perforation is due to the length of the microtunnel to which the effective length of the TBM is added (about 9 m). The pushing amounted to a value close to 600 kN and grew with quite a linear trend, net of point variations, to arrive at the end of the drilling at a value of 800 kN. However, peaks of thrust of a limited entity were detected in correspondence with the starting push after each long interruption of work.

The average feed rates were around 50-60 mm / min. with an average thrust time for each segment of approximately 60 min. The cutter head drilled with an average rotation of 5-5.5 rpm.

The water head of the soil reached, at the point of greatest depression of the route, the value of 0.29 bar in line with the height of the groundwater detected during the preliminary surveys.

The guidance system, composed of a series of prisms placed in front of and behind a robotized station, allowed the laser pointing from this station to a target rigidly fixed to the TBM that allows the continuous control of the drilling trajectory with centimetric precision. These indications allow a precise execution and a constant correction of the deviations to which the TBM is subject. Figure 3 shows the trend of the deviations (expressed in mm) with respect to the optimal trajectory represented by the ordinate line 0.

There are jumps in the data at 80m and 125m approximately due to the calibration carried out following the topographic control measurements, with a maximum entity equal to 25-30 mm.

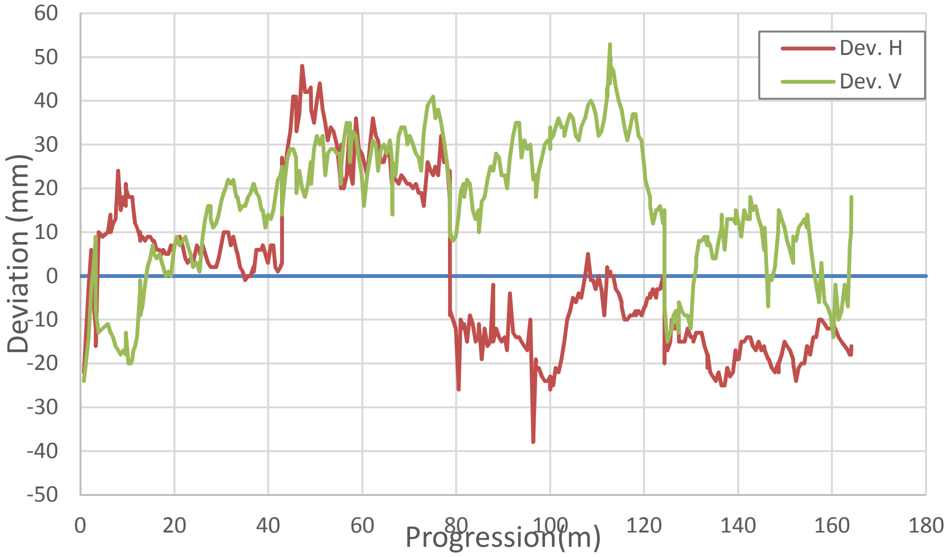

Figure 3. Trend of horizontal (H) and vertical (V) deviations depending on the progression of the drilling

Once the drilling was completed, the TBM was recovered and all the necessary activities were carried out to deliver the microtunnel to the customer ready for the subsequent assembly operations of the pipeline.


Figure 4. The cutter at the end of the drilling – Figure 5. Alignment of ashlars in the microtunnel

Figure 5 shows the alignment of the ashlars in the microtunnel and clearly highlights the accentuated vertical curvature radius that characterizes this crossing.

3. MECHANICAL WORHS

Once the civil activities were completed, the mechanical activities necessary for the installation of the DN 1400 (56” line pipeline) within the microtunnel immediately followed.

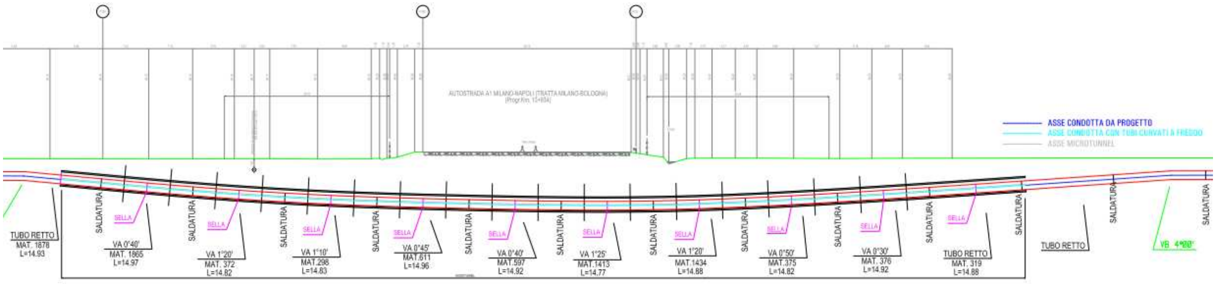

Figure 6. Diagram of bending conducted for the installation in the microtunnel

Preparing curved bars
First of all, it was necessary to prepare the bending plane of the bars and therefore a precise survey was made of the profile of the previously constructed microtunnel, on the basis of which the bending plane of the tube bars was prepared (figure 6.).
Therefore, on the basis of the bending plan, all the 10 pipe bars to be installed in the microtunnel were cold-curved according to the diagram below (figure 7.).

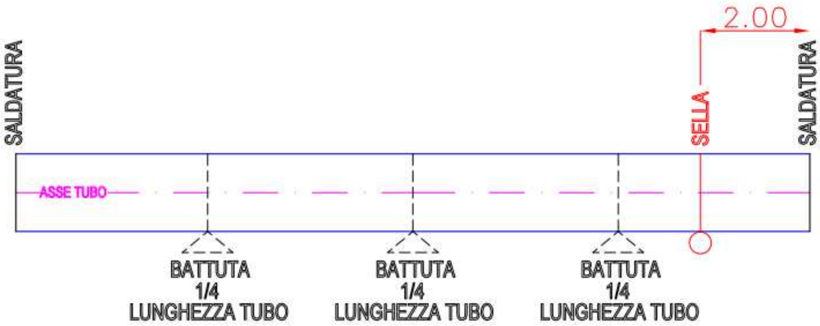

Figure 7. Diagram of cold-curved bars

Each bar was divided into four parts obtaining n. 3 stop points where the pipe was bent one third of a degree for each point.

Main technical data of mechanical activities
The main technical data of the pipe to be installed and of the installation are shown below:

- Pipe outside diameter 1422.0 mm
- Pipe internal diameter 1378.4 mm
- Pipe thickness 21.8 mm
- Material EN L 450 MB (STD API 5 l Grade X60)
- bare pipe weight 752.70 kg/m
- Coated pipe weight 768.89 kg/m
- Launching saddles weight 14.5 kg/m (types of saddles Gauthier – 210056A)
- Laurini winch 150 t
- Bar average length 14.5 m
- Curved bars used no. 10
- Straight bars used no. 2

 

Figure 8. Winch in position – Figure 9. Section of the pipe during the installation phase

Preliminary activities

Once the surveys were carried out and the tube bars were bent, the preliminary activities were started.

The pulling winch was installed inside the push station previously used for the construction of the microtunnel and the tow cable was appropriately laid inside the microtunnel itself. The cathodic protection system was implemented; all the service pipes for the telecommunication cables and for the subsequent clogging were installed.

On each bar (with a wheelbase of approximately 14.5 m), in order to safeguard the passive protection coating and reduce the friction between the pipe and the bottom of the tunnel, some - 210056 type slides were pre-installed. They were made of steel and equipped with rollers so as to considerably reduce the friction coefficient and consequently reduce the pipeline movement efforts within the tunnel during the installation phase.

The shells forming the slides were tightened with a torque wrench (tightening torque of 100 Nm) and a layer of elastomeric material was inserted between the shells and the pipe.

The bars, previously cold-curved, were welded two by two (forming double joints), to optimize the following installation operations. The first and last of the double joints consist of a straight bar and a curved one.

Preliminary tests for the installation of the pipeline

Before starting the installation of the pipeline, a technical report was prepared with the calculation of the stresses needed to install the pipeline inside the microtunnel.

Experimental tests and previous installations carried out by the Contractor showed that the maximum friction coefficient during the pulling operations was 0.04, while the minimum coefficient (measured during the movement) was 0.02.

For the dimensioning of the pulling parts the friction coefficient was considered cautiously equal to 0.05, while to hold back the pipeline the coefficient used in the calculations was equal to 0.00 (in favor of safety).

CALCULATION DATA:

- T tension during pulling
- W pipe unit weight (or section considered)
- L tunnel length (or section considered)
- φ inclination of the microtunnelling (in the section considered)
- μ coefficient of friction collars / tunnel bottom

in the most severe condition (carried out entirely inside the tunnel), we have:

$$T_{\max} = \sum_i T_i = \sum_i W_i \cdot L_i \cdot \left(\mu \cos \varphi_i - \sin \varphi_i \right)$$

The following graph shows the resulting stresses both with the maximum presumable friction (0.05) and with zero friction (0.00), in case of negative sign the pipeline must be held back.

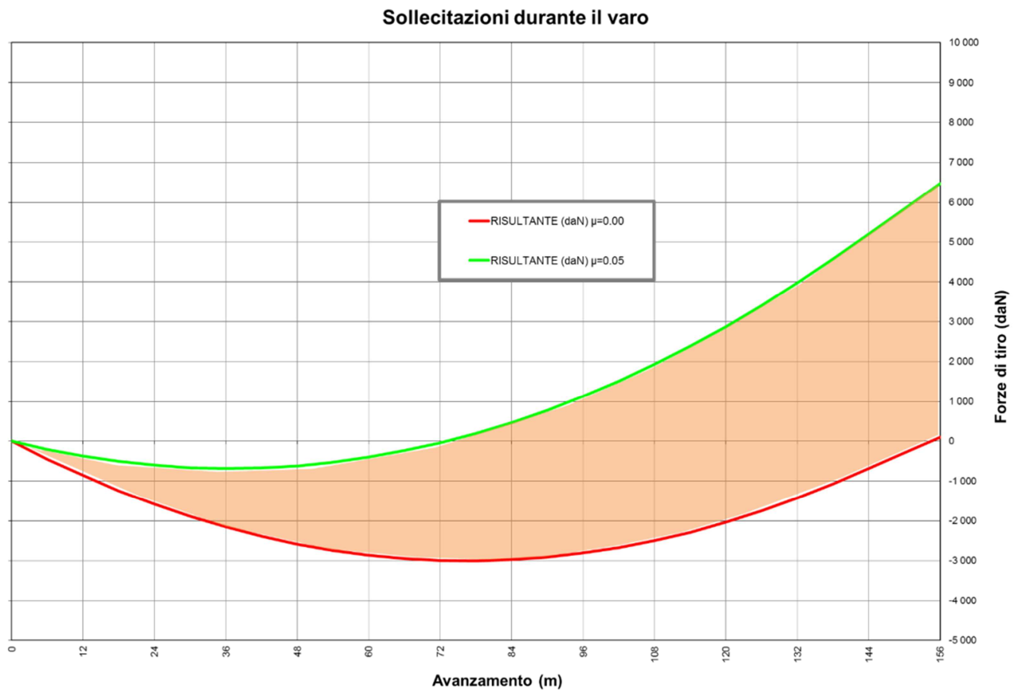

Figure 10. Stresses during installation

The analysis of the results of the above calculation shows that:

- considering the dynamic rolling friction equal to 0.00 the pipeline must be held back for a maximum stress of 3 t (from the calculation 3.000 kg);
- considering the static friction equal to 0.050 the maximum pulling stress is less than 6.5 t (from the 6.477 kg calculation), during the last phase of the installation.

Based on the above, the winch at our disposal is oversized compared to the pulling stresses necessary during the pipeline installation activities.

The installation of the line pipeline inside the microtunnel

Once the preliminary activities were completed, the pipeline was installed.

As previously defined, the installation was carried out with sections of pipe consisting of double joints of approximately 29-30 m in length. The installation of the pipeline took place by drawing each double joint inside the microtunnel, by means of a pull winch placed at the trap where the drilling was started.

Given the geometrical conformation of the tunnel, as it was possible (also on the basis of the aforementioned calculations, despite being carried out with precautionary coefficients) that during some phases of the installation the pipe could continue to advance after stopping the pulling, systems of static blocking were added.

A blocking system consists of a working means that will guarantee the control of the progressive advancement of the rope in dynamic conditions. Furthermore, a clamp with side wings was fixed to the end of the double joint to ensure safety in static conditions. The clamp was fixed to the vehicle used for the blocking with two steel cables fixed with appropriate eyebolts and, at the opposite end, fixed to the hook of the vehicle itself. The purpose of the clamp was also to stop the advancement of the pipe at the end of each pulled pipe, in the right position for the welding of the next double joint.

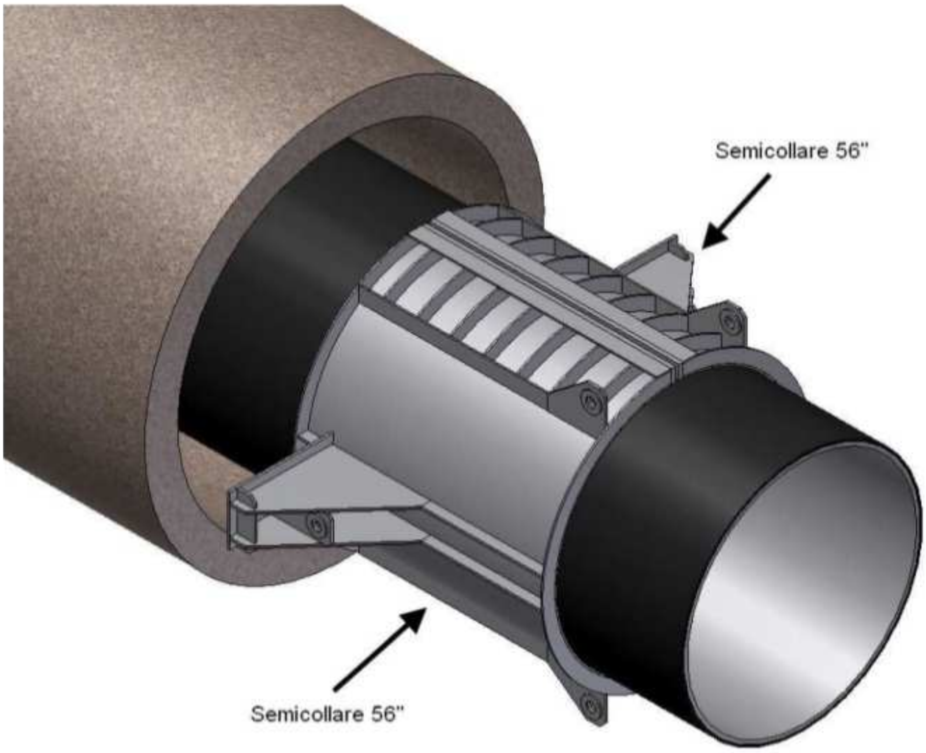

Figure 11. Blocking clamp

Each double joint was installed individually in the microtunnel until it reached the position required to weld the next section. This operation was repeated until the installation was completed.
In this phase, in addition to keeping the pulling stresses constantly checked by means of a dynamometer, it is essential to ensure that the pipeline is always aligned, carefully avoiding any possible rotation.
Since the pipe bars are curved, the curvature of the pipe must be perfectly aligned with that of the microtunnel (perfectly vertical) for the entire installation phase. On the contrary, if the curve were offset, there could be the blocking of the installation itself.
In this phase a special pendulum controlled the verticality of the curve at each stage. In case of deviation it was possible to realign the two curvatures thanks to the blocking clamps.

Figure 12. Pendulum for verticality control - Figure 13. Launching head inside the microtunnel

Final complementary activities
Once the pipeline installation activities were completed and the necessary controls were carried out, further activities were done to complete the installation, such as:

- Hydrostatic testing of the pipeline;
- Clogging of the microtunnel with a special cement mixture;
- Demolition of the microtunnel push station;
- Connection of the pipeline installed in the microtunnel with adjacent sections of pipeline;
- Restorations of the areas and putting the pipeline into operation.

Figure 14. The final phase of the installation

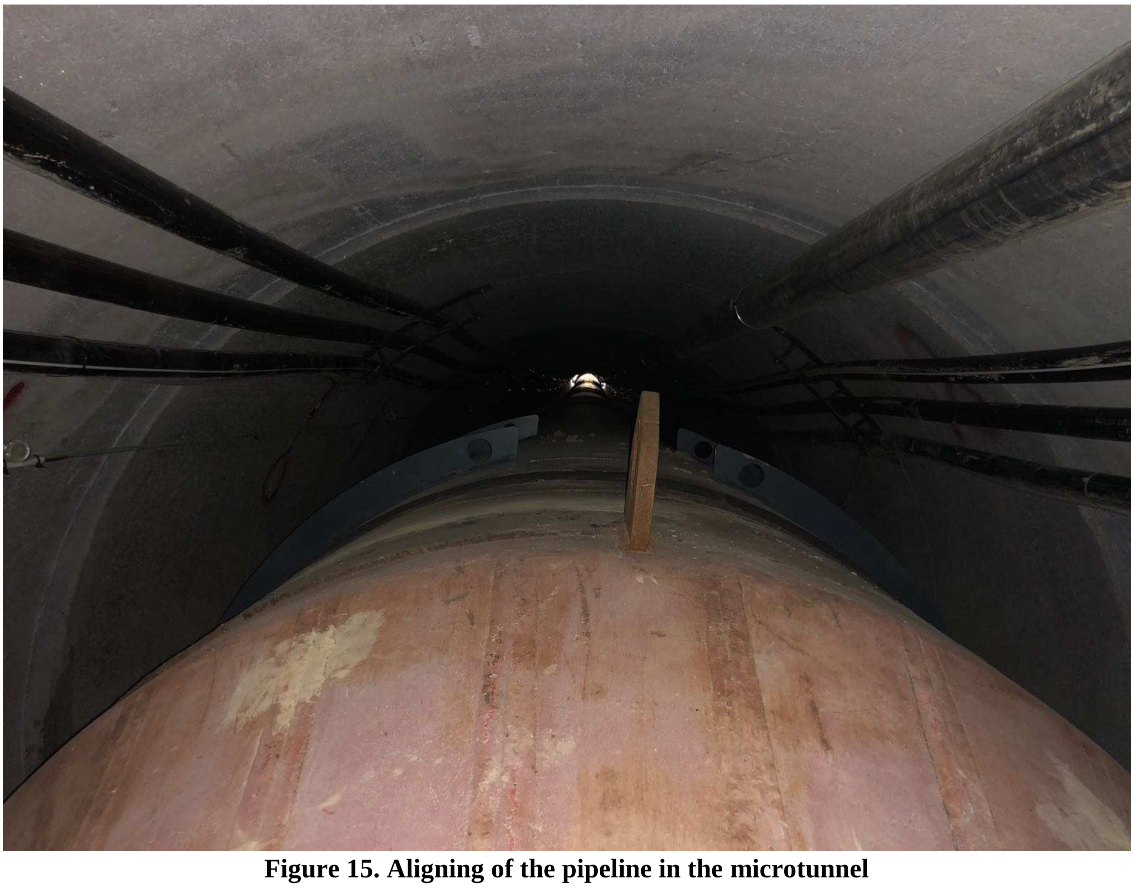

Figure 15. Aligning of the pipeline in the microtunnel

3. CONCLUSIONS

The crossing of the A1 highway, the first microtunnel for a large diameter pipeline built with a reduced radius of curvature ever realized, was a success.

It was possible to achieve it with:

- Extremely reduced length, only 156 m;
- Reduced realization times;
- Low realization costs;
- Small and shallow pushing station, without interference with groundwater level;
- Receiving station not required, only visible excavation for the recovery of the cutter;
- Absolute realization precision.

All this was possible not only thanks to the designers' foresight, but above all thanks to the great professional competence of the staff employed both by the subcontractor ICOP S.p.A. for the very precise realization of the microtunnel, and by the staff of the Contractor Max Streicher S.p.A. for installing the pipeline inside it..

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