A PERMANENT CIRCULAR DIAPHRAGM WALL WITH UNREINFORCED CONCRETE FOR THE GRAND PARIS EXPRESS

Pauline Canto, Soletanche Bachy France, Chassieu, France, +33478315171, pauline.canto@soletanche-bachy.com
Marion Le Batard, Soletanche Bachy France, Rueil Malmaison, France, +33147764262, marion.lebatard@soletanche-bachy.com
Paul Vidil, Soletanche Bachy France, Rueil Malmaison, France, +33147764262, paul.vidil@soletanche-bachy.com

ABSTRACT The Grand Paris Express is the largest transport project in Europe consisting in the creation of 68 new stations and 200 kilometres of additional automatic metro lines in the French capital. The 1501P ancillary structure, part of work package T2A of the Grand Paris Express southbound line 15, is a circular diaphragm wall of 19 m diameter, 1.20 m thick, and 65 m depth. Thanks to a favourable hydrogeological context and the circular shape of the diaphragm wall making this type of retaining works self-supporting for the 57 m high soil excavation, strong technical optimisations have been made on this project. Half part of the reinforced steel cages and a 0.4 m lining wall for the internal civil engineering (which represents 292 m^3 of reinforced concrete) have been removed in comparison to the original planned design, while respecting applicable French standards. The ancillary structure 1501P will be the only permanent structure of the T2A project to be partially composed of an enclosure formed by an unreinforced diaphragm wall, which is the first in France.

Keywords: circular diaphragm wall, unreinforced concrete

PROJECT OVERVIEW

The Grand Paris Express is the largest transport project in Europe consisting in the creation of 68 new stations and 200 kilometres of additional automatic metro lines in the French capital. The main objectives of this large-scale project are to relieve existing metro lines congestion; develop socioeconomic exchanges with the peripheral suburb, and limit air pollution due to intensive traffic in the city. The work package of T2A of the Grand Paris Express southbound line 15 project comprises (Fig. 1):

- 6.6 km of tunnel;
- 4 new stations;
- 2 connection structures for TBM;
- 1 cut-and-cover tunnel connecting one of the stations to the metro maintenance site;
- 5 ancillary structures for ventilation and emergency exit requirements.

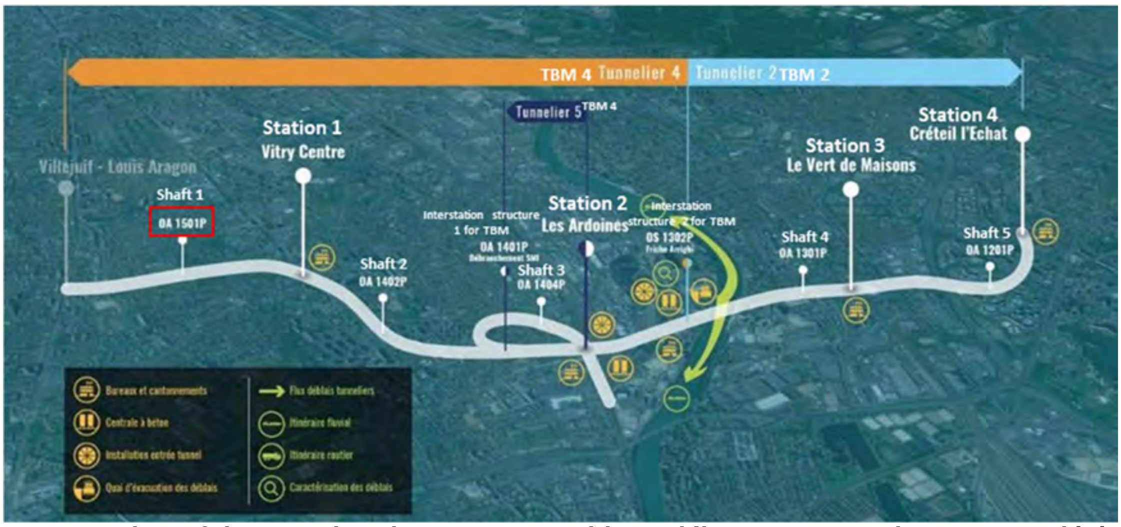

Fig 1 : Overview of the Grand Paris Express southbound line 15, T2A package – © Société du Grand Paris

The 1501P project is one of the five ancillary structures. It is composed of a circular enclosure formed by a permanent unreinforced diaphragm wall, which is a first in France. This 19 m diameter diaphragm wall, 1.2 m thick, and 65 m depth has 14 panels (seven primary and seven secondary units as shown in the Fig. 2) and was drilled in a restricted environment (less than 1,000 m² - Fig. 3).

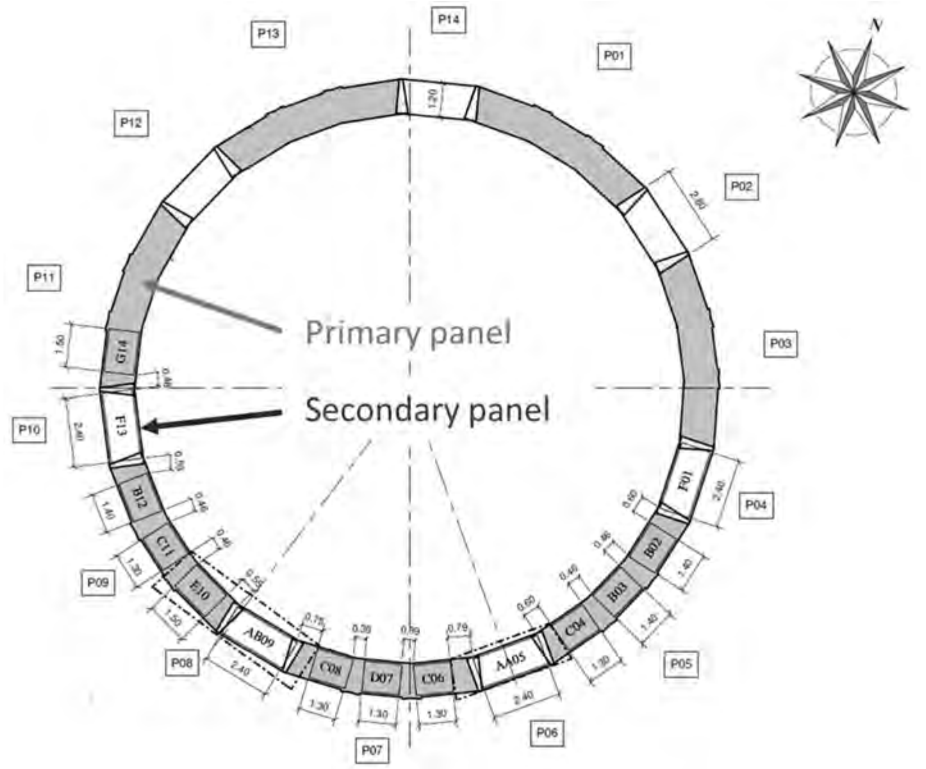

Fig 2 : Plan view of the 1501P - © Soletanche Bachy

Fig 3 : Overview of the slurry wall installation located 360 m downstream from the site - © Cédric Helsly

Interlocking joints were used in replacement to CWS joints originally planned at the design stage. This solution reduced the number of teams working on site at the same time, while avoiding the risks of using 65 m joints in a cramped area. It is with this major constraint in mind that a very detailed analysis was performed to determine where diaphragm wall panel reinforcement was strictly necessary (that is, on half the shaft)

Two access galleries connect the 1501P ancillary structure to the metro line 15 at 45 m depth (Fig. 4). In order to facilitate the excavation of these adits, the steel cages of the diaphragm wall were equipped with glassfiber reinforcement at the opening (and traditional steel reinforcement above and below the openings).

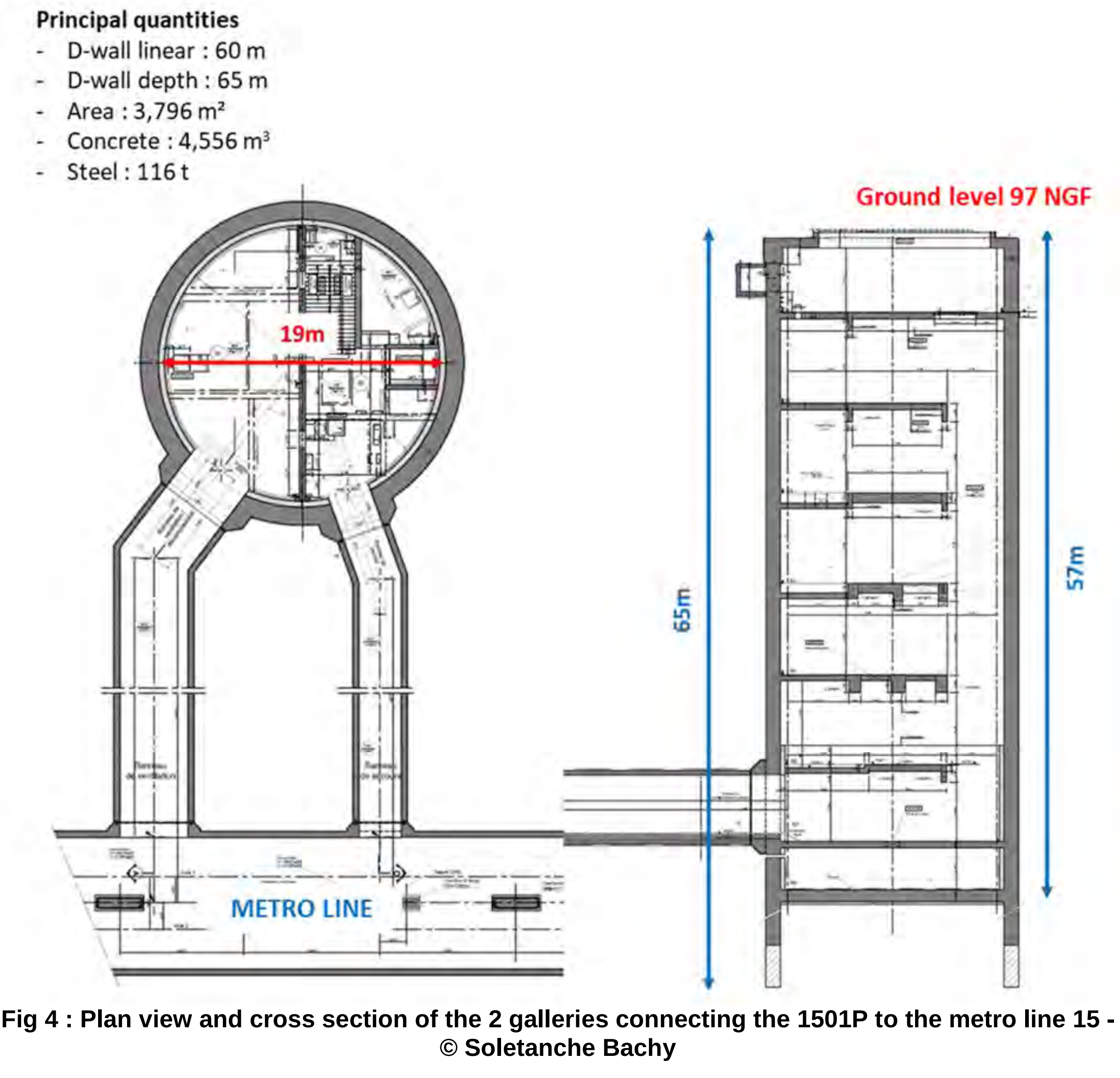

Fig 4 : Plan view and cross section of the 2 galleries connecting the 1501P to the metro line 15 - © Soletanche Bachy

HYDROGEOLOGICAL CONTEXT AND EXCAVATION PROCESS

The stratigraphy is characterized by (from natural ground level – Fig. 5):

- Fill materials – 6 m thick;
- Marly limestones – 6 m thick;
- Green clay – 7.5 m thick;
- Different types marls more or less compact and plastic – 16 m thick;
- A significant layer of marls with alternating gypsum banks more or less friable – 33 m thick;
- Limestones – 22 m thick in which the hydraulic diaphragm wall toe is embedded by 1.5 m.

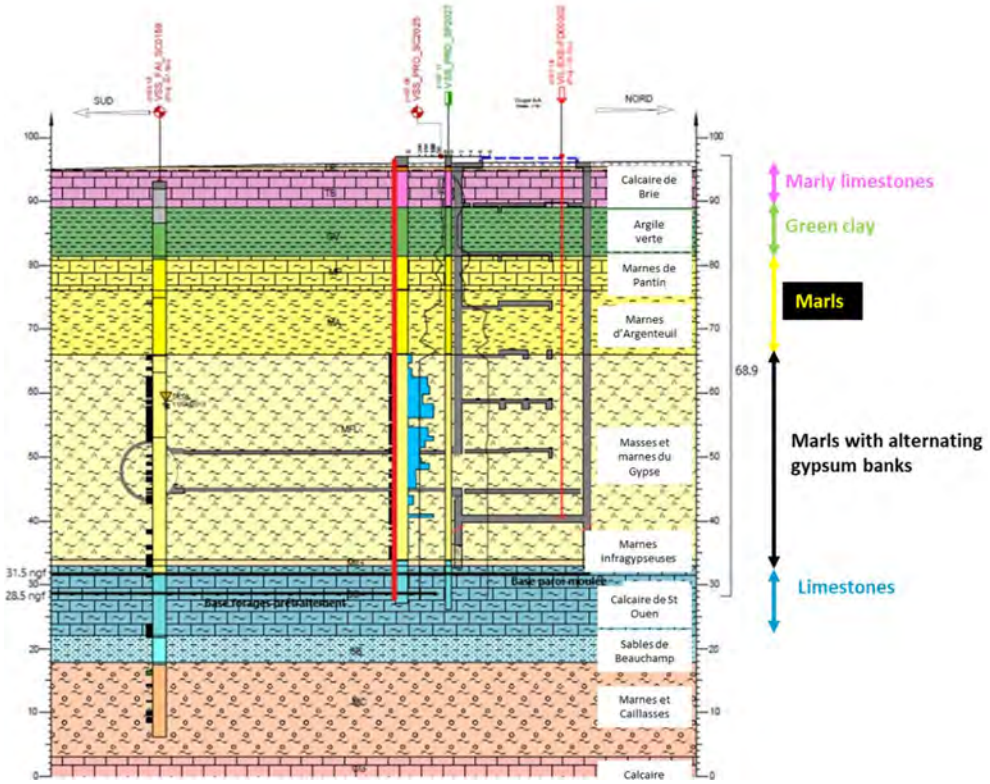

Fig 5 : Stratigraphy cross section - © Société du Grand Paris

Due to the inconsistent stratigraphy, the diaphragm wall was excavated using multiple methods (hydraulic grab and Hydrofraise® - Fig. 6). Primary panels were drilled with hydraulic grab on the first 31 meters more adapted for plastic and clayey soils, followed by Hydrofraise® excavation until the base panels. One meter diameter piles had previously been installed on interlocking panels and backfilled with gravelly materials, which enabled during secondary drilling panels to clean Hydrofraise® drums in a more resistant material, and to reduce pollution effects of drilling bentonite slurry induced by clays.

Fig 6 : D-wall excavation with hydraulic grab and Hydrofraise® - © Cédric Helsly

The 1501P diaphragm wall crosses 3 aquifers. Due to the alternating of soil layers with strong contrasts of permeability properties (ranging from 10^{-5} m/s to 10^{-9} m/s), a specific water pressure profile was considered for retaining wall horizontal stability calculations. Water pressures were relatively low for a 65 m high structure which enabled to limit the vertical bending and did not generate tensile stresses in the diaphragm wall toe. The lower part of the 33 m thick marls layer constitutes a natural low permeable raft which isolates the base of excavation and concrete slab foundation from water inflows coming from the underlying limestone aquifer. No large dewatering device was required during excavation works (just one well equipped with a pump) and there were no uplift issues on this project.

A pre-treatment campaign with twenty-eight 69 m depth-vertical drillings with Hi'Drill® method was made before diaphragm wall works (which represents a volume of 426 m^3 of grouted soil and 1,860 ml of drilling). Pre-injection work was also performed to control water inflows by reducing permeability properties within the marls layer where the two galleries were excavated (a total of 3,390 ml of drillings). D-wall drilling lasted 4 months and was followed by civil engineering construction works (Fig. 7).

Fig 7 : Earthworks and civil engineering works in progress - © Bouygues Travaux Publics

CIRCULAR DIAPHRAGM WALL DESIGN

Circular shafts are designed using arching effect making this type of retaining works self-supporting. Diaphragm wall horizontal stability calculations were studied using 2D soil-structure interaction calculations with the subgrade reaction method, treating the diaphragm wall as a stack of concrete rings with cylindrical stiffness mainly under earth and water pressures.

The circular shape of the shaft is introduced in the analysis by assigning a stiffness depending on concrete Young modulus, wall thickness and shaft radius (=cylindric stiffness) to a continuous elastic vertical support of. The design of a circular diaphragm wall remains easy as long as its geometry and the forces it is under are axi-symmetrical.

As explained previously, two adits are created at 45 m depth for connecting the 1501P ancillary structure to the metro line 15. These openings have different consequences on forces distribution in the structure. Since hoop stresses can no longer be generated at opening level, they must be partially transmitted either side of the openings, which creates (Fig. 8):

- A concentration of hoop stresses;
- Vertical tension in the stress spreading zone (=lintel effect);
- Opening's neighbouring panels have less stiff a support which results in larger radial deflections over the height of the opening and increases curvatures (and consequently vertical bending moments). This stiffness reduction is maximal close to the opening and decreases the further we are from the opening.

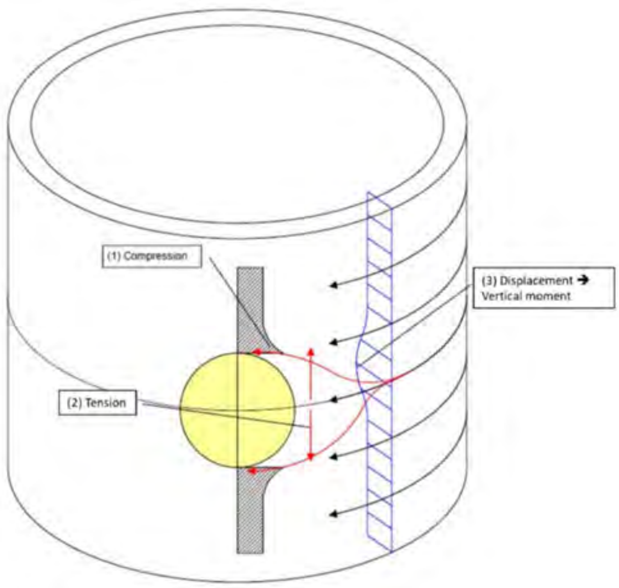

Fig 8 : Impact of an opening on circular diaphragm wall forces distribution - © Soletanche Bachy

This drop of stiffness has been defined thanks to graphs developed by Soletanche Bachy and has led to put steel cages with higher steel ratios close to the openings (=lintel cages) and lower steel ratios away from openings (only 7 diaphragm wall panels were equipped with cages):

- Reinforced lintel cages directly either side of the openings (steel ratio 60 kg/m^3);
- Cages equipped with a mixed element of steel and fiberglass bars on the opening's height to facilitate diaphragm wall opening (minimum steel ratio of 45 kg/m^3);
- Beyond lintel cages, low-reinforced steel cages (ratio 50 kg/m^3).

On the 7 remaining panels, the effects of the openings were negligible and the diaphragm wall bending moments were sufficiently low to justify the other part of the structure in unreinforced concrete in accordance with Eurocode 2-1-1 Section 12 (Fig 9.).

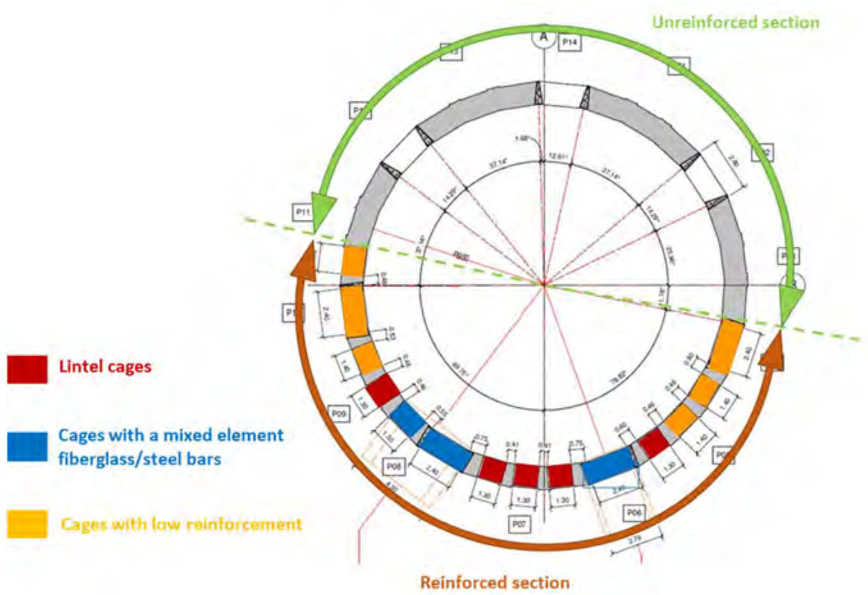

Fig 9 : Steel cages and unreinforced section location - © Soletanche Bachy

Connections between the diaphragm wall and inner civil works slabs were ensured with couplers fixed within cages on the half-reinforced part of the shaft, and with dowels on the other part. The cages were also equipped with reservation tubes for sonic sensors and inclinometers for diaphragm wall monitoring.

A 0.4 m thick concrete lining wall was initially planned at opening's level to reinforce diaphragm wall stiffness (Fig. 10). This lining wall was defined with annular compression stresses calculated assuming a 0.5% tolerance deviation and diaphragm wall concrete design properties C35/45. Compression tests were performed on concrete samples during diaphragm wall works and enabled to redefine diaphragm wall concrete as C45/55 strength class. Moreover, continuous monitoring systems during drilling works limited deviation tolerance diaphragm wall tolerance to 0.15% (70 mm instead of 270 mm in theory). Theses enabled to justify annular compression diaphragm wall stresses without the contribution of the lining wall which could be deleted.

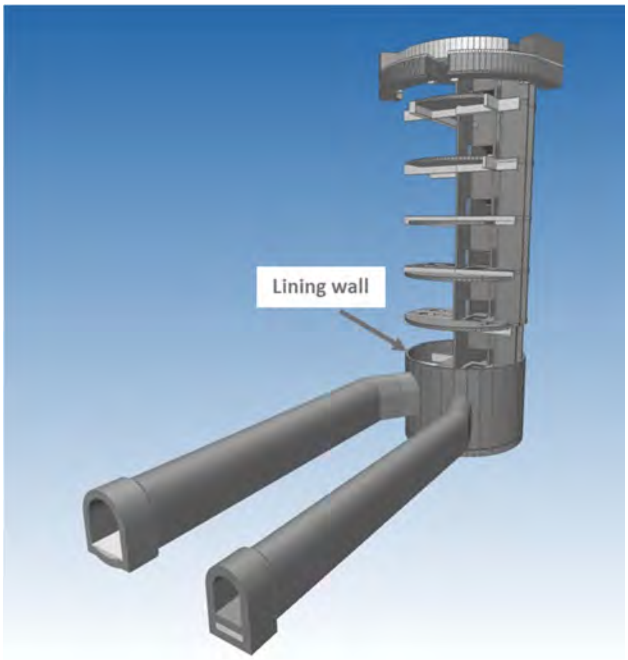

Fig 10 : Lining wall location at openings levels - © Horizon

CONCLUSION

In conclusion, ancillary structure 1501P benefits from technical optimisations which have:

- Reduced construction costs by saving 115 tonnes of steel in the diaphragm walls and removing the need for a lining wall (292 m^3 of reinforced concrete) for the internal civil engineering;
- Reduced the time spent operating equipment and concreting the diaphragm walls;
- Reduced the need for lifting equipment by eliminating half of the wall reinforcement cages as well as the CWS joints;
- Reduced the risks of coating faults and therefore of resurfacing the unreinforced part;
- Reduced transportation by eliminating the reinforcement cages.

This project adds to Soletanche Bachy's experience in reducing the use of resources by only allocating what is strictly necessary, in accordance with applicable standards, particularly through the control of deviations at great depth, as well as the quality of the diaphragm wall concretes.

The next step will therefore be to design and construct a permanent circular diaphragm wall shaft without any reinforcements.