LENGTHENING OF QUESNOY-SUR-DEULE LOCK – DESCRIPTION OF A LATERAL SLIDE CONSTRUCTION

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LENGTHENING OF QUESNOY-SUR-DEULE LOCK – DESCRIPTION OF A LATERAL SLIDE CONSTRUCTION METHOD

by

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ABSTRACT

The French Waterways Authority (Voies Navigables de France) manages in the North of France a particularly active territory in terms of river traffic. The Seine Nord Europe canal project, as a future link between Belgium and France, needs to improve two large-gauge waterways. One of these two itineraries, the canalized Deûle, presents a problematic lock on its route, the Quesnoy-sur-Deûle lock.

This lock is located in France, close to the city of Lille, and less than 5 km from the Belgian border. The problem stands in the fact that this lock has only one lock chamber of 110 m long, while all the others have lock chambers of 144 m. It therefore does not allow the navigation of Large Rhine boats of 135 m, which are very widespread in the Netherlands, Belgium and on the Rhine River. For that reason, BRL ingénierie was commissioned by VNF in 2013 to study the design of the extension of this lock to its new dimensions of 144.6 x 12 meters. The main difficulty for this operation is that the river traffic can only be stopped during a very short period, which should not exceed 2 weeks per year. The second difficulty is that the lock is located in a geological context of Flanders Clay with weak and very particular characteristics.

The proposed solution consists of constructing the walls of the new lock head set back from the chamber lock, under the shelter of two cofferdams and then putting them at their final location by a lateral slide operation. This operation offers the great advantage of providing, in fine, a conventional, reinforced concrete lock, without requiring long closure. However, it induces a certain number of problems to be solved, such as the construction of modular evolutive cofferdams, the placement of tracks and slide bearings capable of bearing loads around 3 000 t, the construction of homogeneous foundations, a phasing of works allowing to work isolated from water, the connection to the existing lock.

The manner in which each of these difficulties has been solved will be developed in the article. The aim of the article is to propose an unusual solution to the problem of the extension of locks with a limited cut-off of the river traffic.

1. INTRODUCTION

1.1. The situation of French waterways in Haut-de-France region

This lock of Quesnoy-sur-Deûle is located in France, close to the city of Lille, and less than 5 km from the Belgian border (**Fig.1**). It is located on the large gauge itinerary of canalized Deûle.
The project to lengthen the Quesnoy-sur-Deûle Lock is part of the reconfiguration mission for the Seine Nord Europe canal and is part of the modernization of the Seine-Escaut connection.
In the context of the increase in river traffic, the objective of the lengthening of the lock is to allow access to Va + units (CEMT ranking) which correspond to the large Rhine boats of 135 m. In addition, it will ensure the continuity of navigation to the large-gauge waterways network, as well as sustain the growing development of river transport.
Indeed, in the context of expected traffic developments with the Seine Nord Europe Canal, inland waterways will be increasingly used in the region (between river ports, major seaports and multimodal platforms) as well as externally to Paris region or to neighboring countries (Belgium and the Netherlands).

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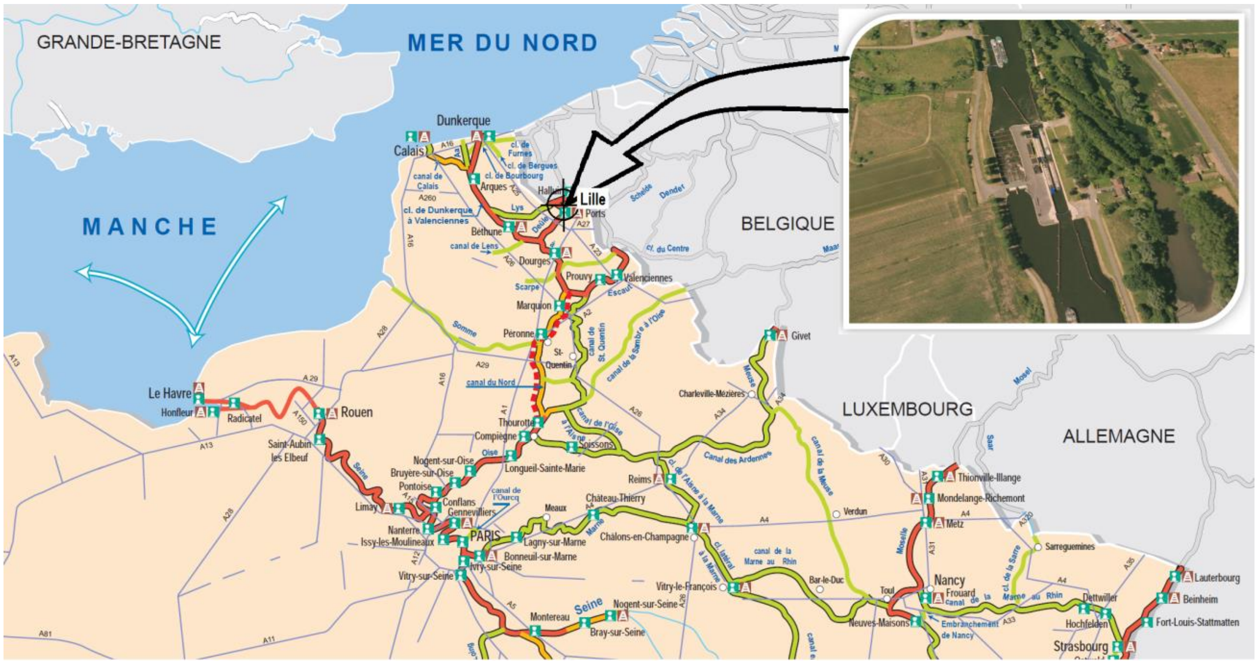

Fig. 1: Quesnoy-sur-Deûle lock site plan

1.2. Quesnoy-sur-Deûle Lock and its length chamber problem

Currently, the Deûle is 1350 t gauge (CEMT IV gauge) and a 3000 t recalibration (110 m long CEMT Va gauge) is in progress.

The lock of Quesnoy-sur-Deûle currently has a lock chamber of 110 m which is compatible with the current gauge but also with the project gauge of 3000 t.

However, as part of the projections for the 4400 t gauge (CEMT Va + - Large Rhine boats of 135 m) and the coherence of the route (the chambers of the other locks on the Deûle upstream of Don and Grand-Carré are 144 m long and the Comines chamber lock on the Lys downstream has just been lengthen to 185 m), a lengthening is necessary to unlock the lock created by Quesnoy-sur Deûle lock.

In a second step, the project of doubling the lock with the construction of a new lock of 190 m will be necessary (studies carried out up to the detailed project stage) by 2040. Thus all the installations related to the works of lengthening of the existing lock must be compatible with the future doubling of the lock.

2. CONTEXT

2.1. Geological context

The geological map of the area (map of BRGM at 1/50,000 scale of Lille and associated legend, **Fig.2**) indicates the following lithology:

- Superficial formation (AO): Modern Quaternary Alluvium (green)
- Alluvial formation (AD): Limons of the plain of the Lys (orange stains)
- Yprésienne formation (AR): Clays of Flanders (orange stripes)
- Landenian formation: a sandy facies with a clay facies base

- Senonian formation: white chalk

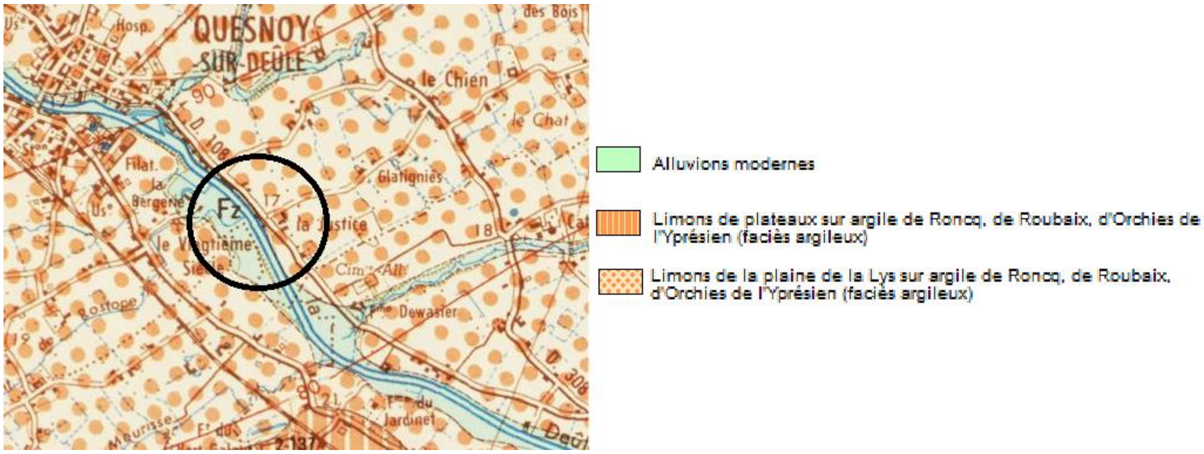

Figure 2: Extract from geologic map of Lille at scale 1/50 000th and associated legend

The tops of the Landenian and Senonian formations are respectively around 35 m and 80 m deep. They were not encountered during reconnaissance. The base of the foundations of the structure is therefore located in the Ypresiennes formations which are very soft clays and which can be very steep whose top is variable (here, between 7 and 12 m of depth).

The superficial (AO) and alluvial (AD) formations are very heterogeneous: a mixture of sands, silts and clays sometimes containing organic matter (for modern alluvium) and relatively poor mechanical characteristics.

2.2 Hydraulic context

At Quesnoy-sur-Deûle, the median flow is 10.3 m^3/s. The navigation has to be possible in normal conditions for the minimal flow rate of 1.72 m^3/s. This flow has to ensure the supply of locks and works linked.
The dams on the river maintain a constant water level. Next to the lock Quesnoy-sur Deûle lock, there is a dam that maintains the upstream levels at 14.72 mNGF. However, the downstream level is not constant as the next dam is far. The target level of the downstream reach is therefore 11.25 mNGF, representing a 3.47 m height drop. Navigation here is allowed up to a 50 m^3/s flow rate.

2.3. River traffic

Today, 13 000 ships per years including 9 000 fully-loaded ships cross the locks. This traffic represents 5 million tons of transported goods. We noted that the annual number of ships has decreased in the past few years, but the annual transported tonnage remains stable; this clearly indicates the growth in ship capacity. In addition, Netherlands and Belgium use a lot of river transport and France projects to develop naval transport in the North. As such, the Quesnoy-sur-Deûle lock is a sticking point as it is the smallest lock on this axis. It limits the length and the number of ships that can pass this channel. Traffic projections suggest that the lock will be overloaded in 2020-2025. This lengthening project is therefore intended to bring the lock to the standard of the others infrastructure on this axis.

2.4. The existing lock

The site of the lock consists of a lock and a dam (**Fig.3**).

The lock. The lock was built in 1980. It has a chamber of 110 m x12 m. The minimal anchorage is 4.30 m. The current structure is "U" shaped, in reinforced concrete. It is about 133 m long. The lock walls are 8.96 m high. The upstream head is equipped with miter gates located on breast wall at 3.75 m height. Two aqueducts, which surround the gate, assure the filling of the lock. Their sections are 2.5 m x2.5 m. They are equipped with two slice gates. The downstream head is equipped with miter gates which have 8 valves to ensure the emptying of the lock. Currently, the filling and the emptying of the lock lasts 5 to 6 minutes. Then, the ship crossing lasts about 19 minutes including ship maneuvers, gates and valve maneuvers and filling or emptying.

The dam. On the left side, a check dam, rebuilt in 2009, composed with 2 passes, has a discharge capacity of 125 m^3/s.

The median embankment. It is located between the dam and the lock. Three premises are built on it: the technical building, the command building and the archive building.

The right bank. Two houses belonging to the site are on the right bank.

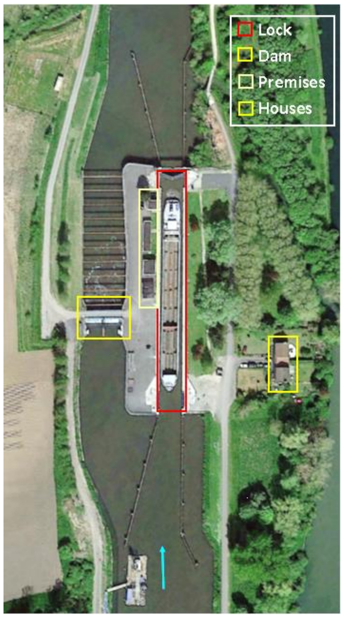

Figure 3: Location of the main facilities on the site

3. THE NEW LOCK

The project consists of the following elements: the lengthening of the lock (**Fig.4**), a fish pass, a pumping station, 2 ship parking areas (upstream and downstream), recalibration of the canal close to the lock in order to have an anchorage depth of 3.50m (760m on upstream reach and 340 m in downstream reach), replacement of guide rails, and refurbishment of three premises.

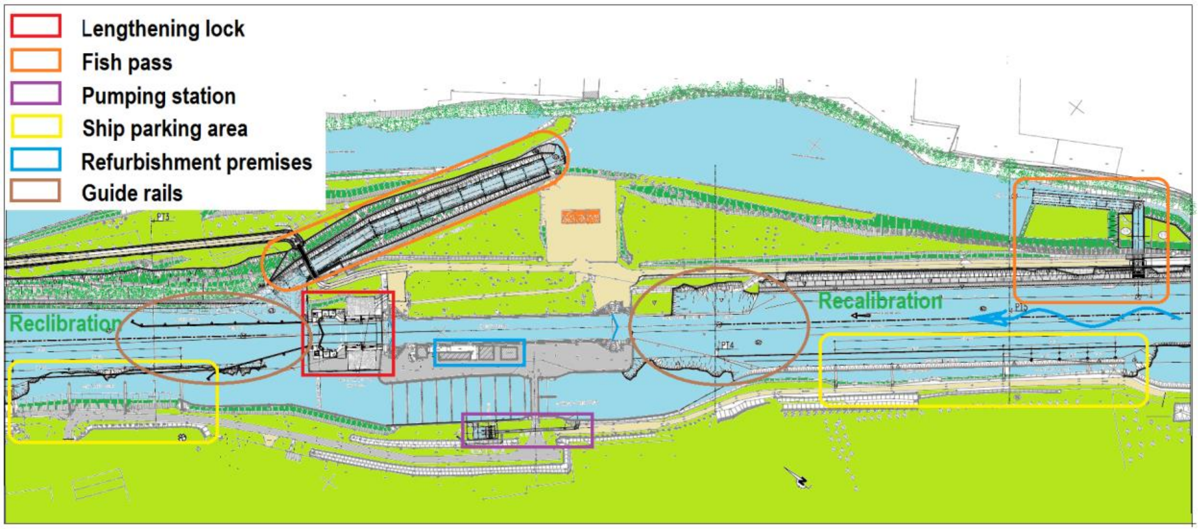

Figure 4: Plan view of the lock site

Only the lock lengthening is described below.

The lengthening of the lock is to take place on the downstream side of the lock to work with lower water level and reduce hydraulic strength, and to avoid deconstruction of the breast wall. The aim of the lengthening is to obtain a usable length of about 144.60 m. Then, the total length of the extension is 39.55 m (**Fig.5**). The shape and the material of lengthening will be identical to the current one: “U” shape (**Fig.6**) in reinforced concrete. It is superficially based on the clays of Flanders.

The common parts (lock walls, invert) and the head block are connected by dimpling system with WATERSTOP sealing strips. These systems allow the independent slipping of the blocks, a mechanical connection which avoids misalignments between blocks, and structural independence which allows shrinkage of concrete without cracks.

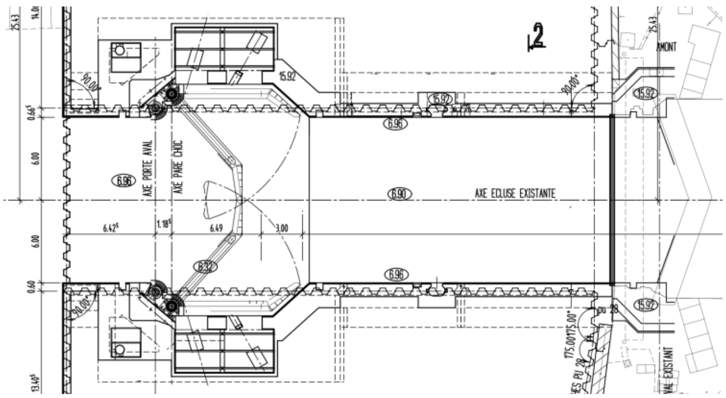

Figure 5: Plan view of lock extension

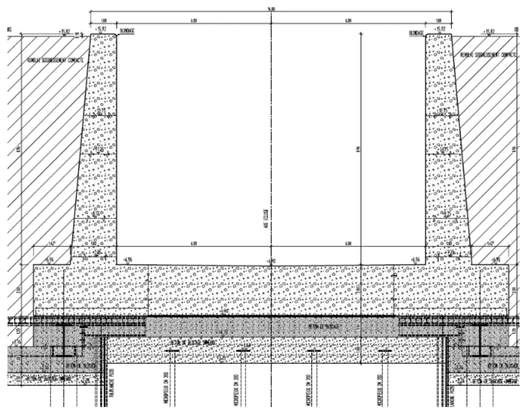

Figure 6: Cross section of the lock extension

The downstream head is equipped with a 20° angle miter gate bearing 6 valves, 3 per leaf, totaling a section of 11.52 m², equal to the current section. The gate is 65 cm higher than the upstream water level and a 1.2 m width walkway is located on top of the gate at embankments level. The actuators are electromechanical cylinders. Their capacity is 20 t and their extension length 2.6 m.

Gate are protected by bumpers. They are composed of 2 pivotal elements that behave more or less like a small gate. Each element is linked to a gate leaf by chain. Then, the gate movement drives the bumper movement. A Jarret damping system equips each bumper leaf. Bumpers can absorb energy of shocks up to 280 KJ.

Guide rails are placed downstream on the lock. They are composed of piles and rails.

The new lock, as described above and with the same valve section as the existing structure, raises the washing out time of the chamber by approximately one minute. The new lock will thus be able to perform a maximum of 41 cycles per day, three less than its current ability.

The projected total for the project is about € 30 M, including tax.

4. CONSTRUCTION DETAILS

4.1. Evolutionary cofferdam construction and construction phasing

The implementation of this extension raises several difficulties. The first is that the average completion time for a traditional reinforced concrete structure like this one is estimated at 4 months. This implies cutting off navigation for 4 months. For the operator, navigation cannot be stopped longer than for a few weeks. It is therefore necessary to find a way to allow construction at the same time as allowing boats to cross. As a matter of fact, the lock walls do not restrict the navigation. However, their construction requires a dry environment, sheltered by a cofferdam. It also requires protecting the workers in the cofferdam against shocks from boats. These constraints require the construction of the basements with a withdrawal of at least 0.70 m from the bare walls of the locks already built (which are spaced 12 m apart). Two solutions are available to the designer: either leave these newly constructed walls in place, or bring them in line with the previous ones. The first solution, although simpler to build, requires the design of a wider door and bumper, as the opening increases from 12 to 13.4 m. In addition, it would create jutting angles in the wall, which would be potential sources of shocks to the boats.

The second solution, presented here after, was therefore chosen:

- in a first step, to build the extension walls in withdrawal of approximately 3.50 m of the existing walls, sheltered by two small cofferdams, one for the left wall and one for the right wall;
- And, secondly, to move each wall - by sliding it on metal profiles - to its final location protected from the water by a large cofferdam uniting the two previous small ones.

These constructive principles led to the establishment of a phasing of work over 3 years including 3 closure periods of respectively 2, 4 and 3 weeks. It is described below

Work during closure period number 1

- Removal of guide rails of the downstream out port and demolition of the downstream slab;
- Partial earthworks in the channel to a depth of 2 m;
- Construction of two cofferdam (**Fig. 7**), one on each side of the channel;
- Each cofferdam has a rectangular plan-view shape of 37.5 m x 13.2 m; The 2 cofferdams are spaced 13.1 m apart; The sheet piles (PU28) have a height of 20.5 m;
- Implementation of micro piles at the chamber location according to a 2.75 m square mesh.

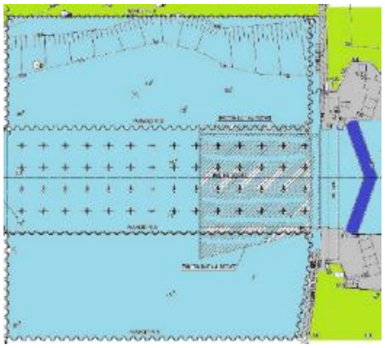

Figure 7: Closure period 1 - View of the two small sheet pile cofferdams

Work during the intermediate period between closure periods 1 and 2

This period has a projected duration of 11 months.

- 1st phase of earthworks in water over 5 m inside the 2 cofferdams;
- Driving of steel piles of the temporary support system;
- After dewatering, placing the walling, struts and tie rods at the lower walling, on the sides facing the banks;
- 2nd phase of earthworks under water (height 5 m), casting of a 0.50 m thick concrete layer and dewatering of the 2 cofferdams;
- Cutting of piles upper parts, setting of the temporary support structure and casting of a 1 m thick layer of concrete all around falsework;
- Lock wall construction (**Fig. 8**).

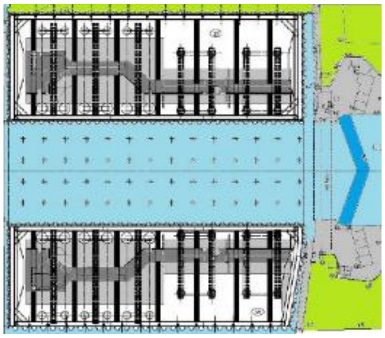

Figure 8: Works between closure periods 1 and 2 - View of the walls built back from those of the existing lock

Work during the closure period number 2

- Driving of 2 sheet pile walls to connect the 2 small cofferdams, one upstream and the other downstream;
- Partial dewatering and setting of I-shaped walling with variable height (0.90 m / 1.70 m) on both walls. Walling is held by 2 Ø800 struts.
- Earthworks under water in the central box;
- Casting of blocking concrete 1 m thick at the chamber emplacement & dewatering;
- Cutting of the intermediate sheet pile walls located on both sides of the chamber area and removal of associated walling and struts; obtaining a cofferdam of 37.5 m x 39.5 m;
- **Sliding of the walls: blocks 1 and 2 and head block;**
- Removal of sliding rails and implementation of concrete under the walls;
- Building of the central part of the invert;
- Building of the connection between lock blocks and sheet piles walls upstream and downstream;
- Filling of the new chamber; disassembly of the walling and struts Ø800 in the chamber;
- Cutting of upstream and downstream sheet pile walls in the chamber; Opening for navigation (**Fig. 9**).

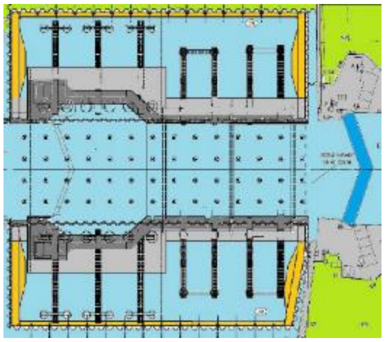

Figure 9: View of the work at the end of closure period 2

Work during the intermediate period between closure periods 2 & 3

- Finishing the lock walls and implementation of tie rods between left lock wall and the left bank sheet pile wall.
- Backfilling of the two small cofferdams (**Fig.10**)**.**

Figure 10: View of the work at the end of the intermediate period 2/3

Work during the closure period number 3

- After setting maintenance cofferdams and dewatering, connection of the extension to the old lock.
- Equipment installation (gate, bumpers, operating devices);
- Filling of the chamber and opening for navigation.

The phasing is summarized in the table next page (**Fig.11 to 19**).

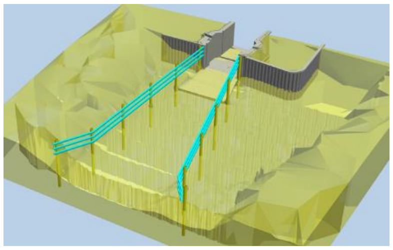
Figure 11 - Phasing - Stage 0

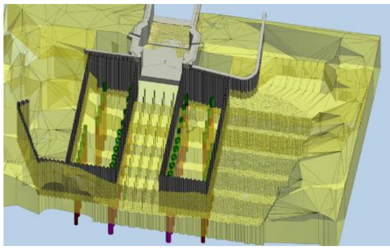
Figure 12 - Phasing – Closure period 1 – Smalls cofferdams and piles

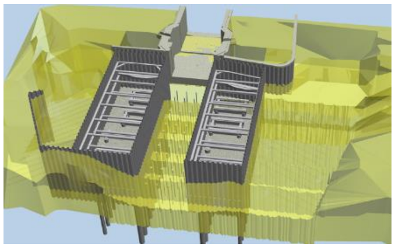
Figure 13 - Phasing – Intermediate period between closure periods 1 et 2 – Lateral slide tracks

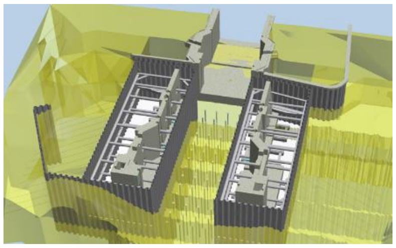
Figure 14 - Phasing - Intermediate period between closure periods 1 et 2 - Walls

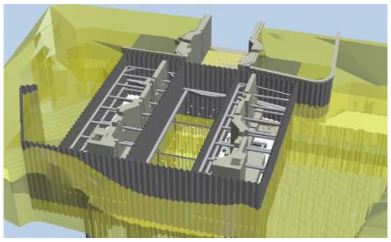
Figure 15 - Phasing – Closure period 2 – Unification of small cofferdams

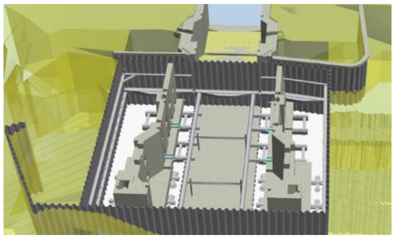
Figure 16 - Phasing - Closure period 2 – Realization of the large cofferdam

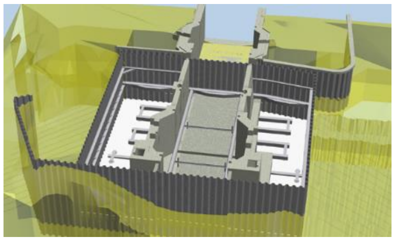
Figure 17 - Phasing - Closure period 2 – Sliding of the walls

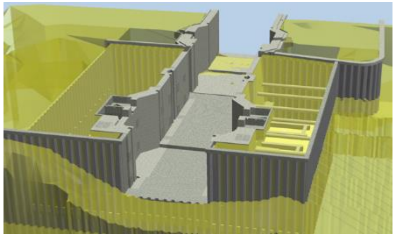
Figure 18 - Phasing - Intermediate period between closure periods 2 and 3 – Embankments

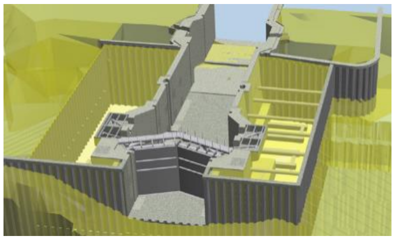
Figure 19- Phasing - Closure period 3 – Connection structure and gate

4.2. Implementation of sliding rails

Sliding structure

The large concrete slab at the bottom of the excavation is based on the clays of Flanders. The bearing capacity of these clays is too weak to withstand localized efforts during the shifting phase. This is why foundation piles are planned to support the beams of sliding.

For each line of wall, two rows of piles are planned: a line of front piles, at the limit of the lock chamber, and a line of piles behind the walls. The two lines are 9.2 m apart. These rows of piles are connected by I-shaped metal beams, 1.25 m high. These I-beams are laid on reinforced concrete plugs connected to the piles. These beams support the sliding rails. These are metal box girders of section 0.75 m x 1.25 m (b x h). Three sliding beams are planned for the head block wall and 2 beams of sliding for each current wall. A beam under the head block has to support a load of 1000 t. During construction, and up to the start of sliding, the mass of the walls is distributed more or less equitably between the two rows of piles. During sliding the mass of the walls will be carried toward the chamber lock. The latter supports more than 80% of the load at the end of sliding. This is why the piles of this row are designed to each support a load of 500 t. These are steel piles with a diameter of 1400 mm. For the line back of the lock chamber, we adopt piles of 250 t unit capacity and 1000 mm diameter. As the expected masses of the current blocks are much lower, 1000 mm diameter piles will be sufficient for both front and rear.

The beams are surmounted by sliding rails. These are beams made of 2 HEM 260 profiles welded side by side. The sliding of the lock walls is carried out on these sliding rails.

Sliding operations

Pushing is carried out on each rail by means of a jack fixed between the wall and the rail. The body of the jack is fixed on a metal shoe itself bolted to the rail. The cylinder head is attached to a metal bearing anchored in the concrete of the lock wall.

The walls lie on the rails via plates embossed on the underside and coated with PTFE (brand "Teflon"). The friction on the rails is therefore limited to about 15% at startup and 5% in sliding phase, which allows the use of double-acting jacks of 300 t capacity. The progress will be obtained by steps of 300 mm, all jacks pushing at the same time, according to the following cycle:

- The shoes are bolted on the rails, 300 mm translation of the lock wall by jacking out;
- Unbolting and translation of the 300 mm shoes by jacking in;
- Bolting of the shoes.

The wall must be able to be vertically jacked at all times in order to allow the lubrication of the rails or the transversal adjustment of the load. For this purpose, 4 jacks per rail will be provided.

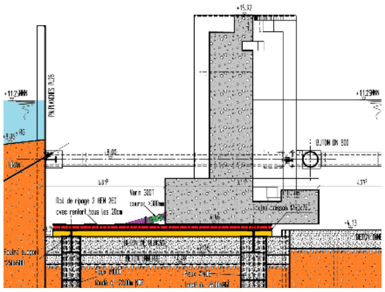

Figure 20: Lock wall in its final sliding position

Setting on final bearings

At the end of sliding the remaining gap between the walls inverts and the concrete layer is filled with mortar (coarse concrete aggregate or lean concrete). The sliding rails and jacks are then removed. Spaces left empty are filled with mortar.

4.3. Arrangements to respect short closure periods

In the context of intense river traffic at the lock of Quesnoy-sur-Deûle, strong constraints are imposed to keep navigation closures to a minimum.

Thus, these closure periods should be reduced to 3 - spaced by about 1 year - limited to respectively 15, 30 and 20 days. Closures of 30 days being extremely restrictive for the operator of the waterway, the increase of the duration of closure beyond 30 days is not possible.

Thus steps have been taken to respect these time restrictions:

- Optimization of working days during closures with the inclusion of 6 days of activity per week and shift work whenever possible (demolition operations and earthworks in 3 shifts, piles driving operations in 2 shifts, but lateral slide and electricity operations in one shift).
- Performing a sliding test before the start of the 2nd closure period in order to avoid losing time during the actual sliding during closure.

- Definition of a point of no return for the key closure period, namely the second one, which consists in the possibility of taking a decision according to the actual progress on the 10th day of the period (i.e. the large cofferdam must have been dewatered by this date at the latest):
  - Either continue the work and complete the work within the time limit;
  - Either stop the work and return to navigation prematurely and lose the slot of closure expected. This alternative, even if anticipated, is obviously not desirable and will be the subject of dissuasive penalties.
- Consideration of margins respectively of 2, 3 and 2 days for closure periods 1, 2 and 3 in order to control a skid of the schedule.
- Development of a detailed program on a daily basis as early as the detailed project phase to ensure the feasibility of operations to be carried out under closure within the deadlines.

4.4. The clays of Flanders

Presentation of the issues

Feedback on the sector (construction of the dam on lock site in 2009 and implementation of sheet piles upstream of the lock on the left bank in 2015) and more generally on the region (different sheet pile construction sites) have shown that the completion of sheet piles driving and / or tie rod grouting work in the clays of Flanders could present risks in the construction phase which must therefore be anticipated.

The design of geotechnical structures (cofferdams, micro piles and grouted tie rods) allowing the lengthening of the lock to be completed therefore requires:

- For the cofferdam and the piles of the falsework: The implementation of relatively heavy profiles throughout a great height of Clays of Flanders. Indeed, the piles are 30 m long and the sheet piles (a linear of 275 ml) are 20 m long. The plastic and stiff nature of these soils induces a significant risk of refusal. The sheet pile profiles have therefore been chosen to safely allow their resistance to the forces generated during implementation.
- For tie rods: performing grouting in clay soil may become problematic because of the presence of sensitive structures located in the immediate vicinity (namely the existing lock). Indeed, the tie rods (28 in number) are 25 m in length, including 17 m of sealing in Flanders clays with risks of "breakdown" of the ground under the effect of grouting. This risk is even higher as the injection mode envisaged in the project is the “Repetitive and Selective Injection” which requires a good management of the injection pressure in order not to slam the clays. This is especially critical since clays have pressure limits relatively close to the injection pressures used for the implementation of this technique. However, since the tie rods were not executed under the existing lock, this risk remains relatively unlikely.

Management of the risk of refusal

In order to guard against the risks of a mismatch of the driving technique, the drill capacity or the choice of profiles with the geotechnical context, a preliminary driving test is therefore planned before the procurement of works to ensure the feasibility of the works envisaged at the project stage. This driving test will include the registration of a 30 m and 1000 mm diameter pile and 8 PU28 sheet piles (4 pairs). It will also make it possible to carry out vibration measurements on the existing lock in order to ensure there is no risk of disturbance on the existing lock and its current equipment.

Management of the risk of displacements related to the realization of work

In addition of specific monitoring of the injection pressures of tie rods, displacements measurements will be made on the existing lock chamber (gate and walls) continuously during the work to manage the risk of displacement. The threshold alert will be set at 8 mm and a critical threshold at 10 mm.

Management of the risk of displacement of the bottom of excavation

There is a risk of desiccation of clays from the bottom of the excavation which may later cause the structure to move. To limit the phenomenon, earthworks in cofferdams will be completed under water and covered with concrete plug – also cast under water - before dewatering.

4.5. The existing lock

Presentation of the problem

The principle is to build the extension of the lock chamber independently of the existing lock. In addition, the downstream head of the existing lock is relatively massive and should not be affected by work downstream. However, the immediate proximity of the chamber of the existing lock requires special attention during the works.

Indeed, the latest work done near the lock (construction of the dam) showed that it could undergo displacements which, at the time, were related to the injection of tie rods under the chamber of the lock. This caused the displacement of several blocks (longitudinal displacements of 1.5 to 2 cm and vertical displacements up to 2.5 cm). At the time, they did not induce structural disorders on the lock nor on these equipment. In addition, the vibrations induced by the driving operations require special attention because of the presence of sensitive devices on the lock in operation (sensors) and risks of resonances (jacks, gate and gateway).

Management of this problem in the works phase

Before the start of the work, a test will be carried out audit the equipment likely to be impacted by the vibrations. Vibrations will be monitored during this test before threshing. If this test is conclusive, the vibration monitoring of the lock during the work will not be necessary. In the opposite case, further investigations will have to be carried out and conservative measures taken (i.e. equipment instrumentation during sheet piles and piles driving, with definitions of alert thresholds and critical thresholds).

In addition, as written above, the old lock will be followed topographically during the works to ensure that the differential movements between the different blocks do not surpass 1 cm.

5. CONCLUSION

Because of its short length, the Quesnoy-sur-Deûle lock is a singularly problematic point for the development of river traffic on the large-gauge network of the Hauts-de-France region. The choice of the building an extension using traditional reinforced concrete having been made, the technique sliding walls will be implemented to minimize closure during construction. The study made it possible to review and provide answers to a certain number of problems which will be generated by this technique, particularly in terms of cofferdam construction phasing, falsework foundation, work in Flanders clays, protection of the existing lock and, above all, respect of the deadlines.

The start of on-site works is scheduled in 2020. The implementation of this project will certainly allow to gain experience for other projects of the same type as there are many other locks to extend on the large-scale network of the region.