# Replacing Existing Lock 4 - Innovative Designs for Charleroi Lock


Authors: Steve R. Stoltz, P.E.

Project Engineer
Pittsburgh District, USACE
Wm. S. Moorhead Building
1000 Liberty Avenue, Room 1934
Pittsburgh, PA 15222-4186
(412) 395-7297

Stephen.R.Stoltz@LRP02.usace.army.mil

Lisa R. Pierce, P.E. and Dave A. Stensby, P.E.
Project Managers
INCA Engineers, Inc.
400 112th Ave. NE, Suite 400
Bellevue, WA 98004
(425) 635-1000

D.Stensby@incainc.com
L.Pierce@incainc.com


## Background

Existing Lock 4, located on the Monongahela River near Charleroi, Pennsylvania, consists of a landside 56-foot x 720-foot main chamber and a riverside 56-foot x 360-foot auxiliary chamber. This lock, shown in Figures 1 and 2, was constructed in the 1930's and is approaching the end of its useful design life.

**Figure 1. Photo of existing Lock 4 on the Monongahela River, near Charleroi, Pennsylvania**

The existing concrete lock walls are founded on timber piles that are currently loaded to their design capacity. In the 1960's, the original fixed crest dam was replaced with a tainter gate dam, and the upper pool was raised 6 feet (an increase of more than 50 percent of the original lift height). Prior to raising the upper pool, concrete floor struts were installed in both lock chambers, and a submerged diaphragm wall, composed of sheetpile cells, was constructed riverward of the lower river wall and guard wall to stabilize the existing walls.

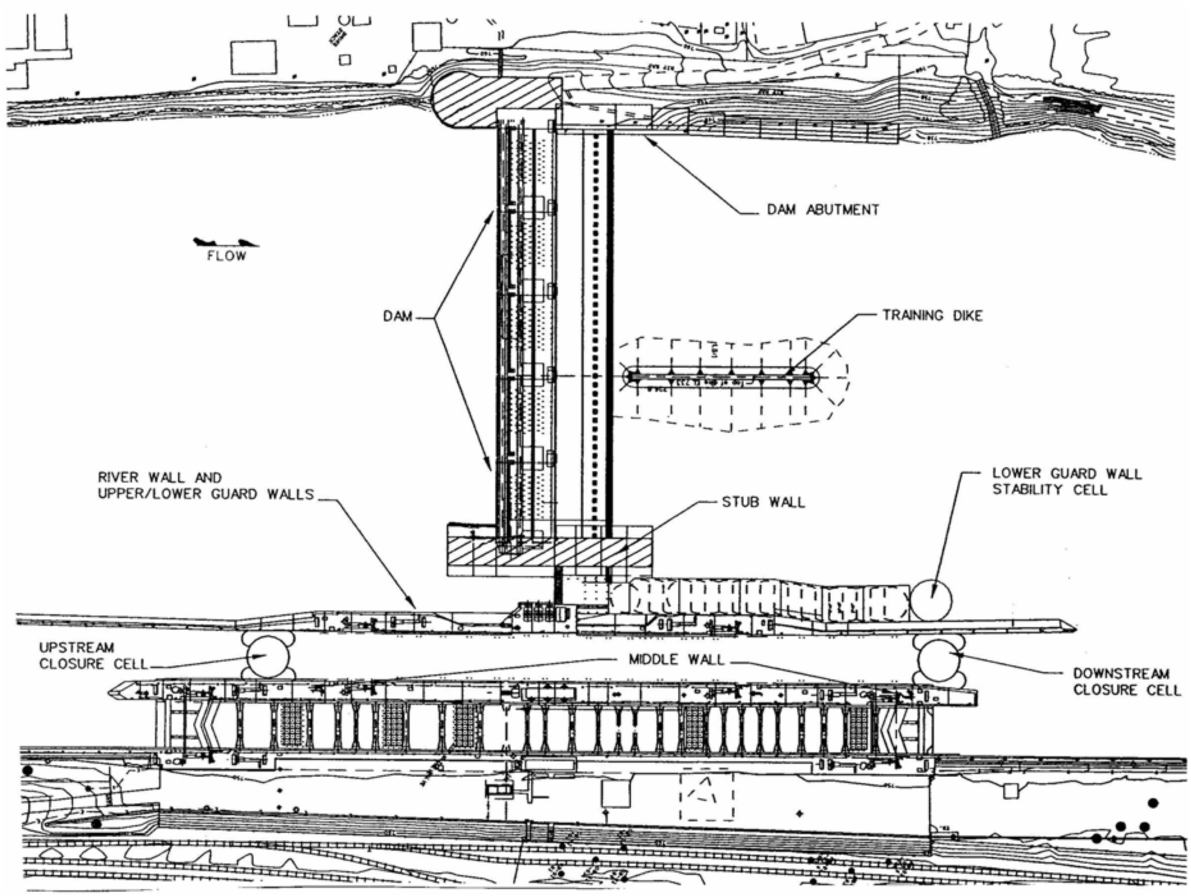


**Figure 2. Plan view of existing Lock 4 after the river chamber stability struts are demolished**

Maintaining stability of the existing lock walls was a critical requirement for the new lock design, as this was necessary in order to continue navigation traffic through the existing landside lock chamber. Since the existing middle wall was stabilized by concrete floor struts, which must be demolished prior to the new lock construction, meeting this stability requirement was very challenging.

Two new lock chambers, each 84-foot x 720-foot, will be constructed at the location of existing Lock 4 and will be named Charleroi Locks. The new lock walls will be founded on reinforced concrete drilled shafts, ranging from 4-foot to 6-foot diameter. The new lock construction will be sequenced such that the existing main lock chamber remains operational until the new river chamber is constructed. Once the new river chamber is in place, the existing land chamber will be closed, and the new land chamber will be constructed. The U.S. Army Corps of Engineers, INCA Engineers, and other consultants worked together to design the new lock structures, which are shown in Figure 3. The first construction contract, for work on the new lock river wall, was awarded in 2004.

Innovative designs, such as a floating guard wall, a post-tensioned box beam guard wall, slip-formed river wall monoliths, and internally braced local cofferbox construction were developed for the new twin lock chambers.

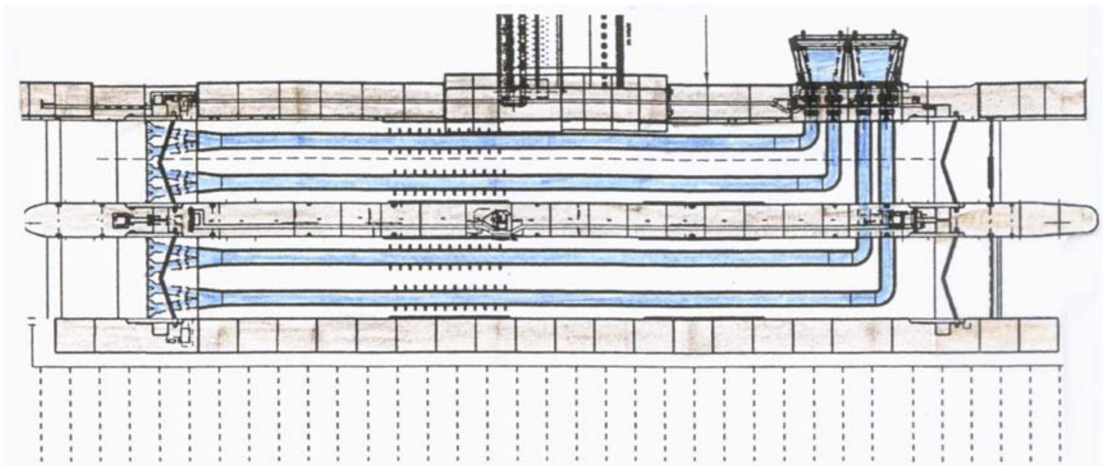

**Figure 3. Plan view of the new Charleroi Lock**

## Internally Braced Cofferboxes

Of these innovative features, this paper focuses on the specifics of the internally braced local cofferbox design and construction procedures, which will be used to construct many of the lock wall monoliths. The cofferboxes will be used to dewater local areas for conventional construction of these lock monoliths. Middle wall monoliths that are located upstream and downstream of the global cofferdam, formed between the existing river wall and the existing middle wall, will be constructed within local cofferboxes. In addition, the following lock wall monoliths will be constructed using local cofferboxes:

- River Wall and Middle Wall Miter Gate Monoliths
- River Wall Emptying Valve Monoliths
- Middle Wall Cross Culvert Monolith

Those monoliths, which will be constructed within local cofferboxes, are shaded in Figure 4. This figure shows both the existing and new lock walls.

Local cofferbox construction provides high quality, monolithic concrete walls (monolithic construction is particularly important for monoliths that are subjected to cyclic loading from miter gate anchorages) while maintaining the stability of the existing lock walls. Methods that used open cut excavation for construction of the new middle wall were not feasible for this project, since the excavation would undermine the existing timber pile-supported middle wall. Local cofferboxes also reduce construction costs and maintain existing navigation traffic by eliminating the conventionally constructed cellular cofferdam. Local cofferboxes are practical for this site because the new river lock is offset riverward from the existing lock, where traffic is maintained during construction. Since the cofferbox must be wider than the finished monolith width, cofferboxes are not as desirable for specific uses, such as middle wall extensions of twin lock chambers, where they would extend into an operating lock chamber.

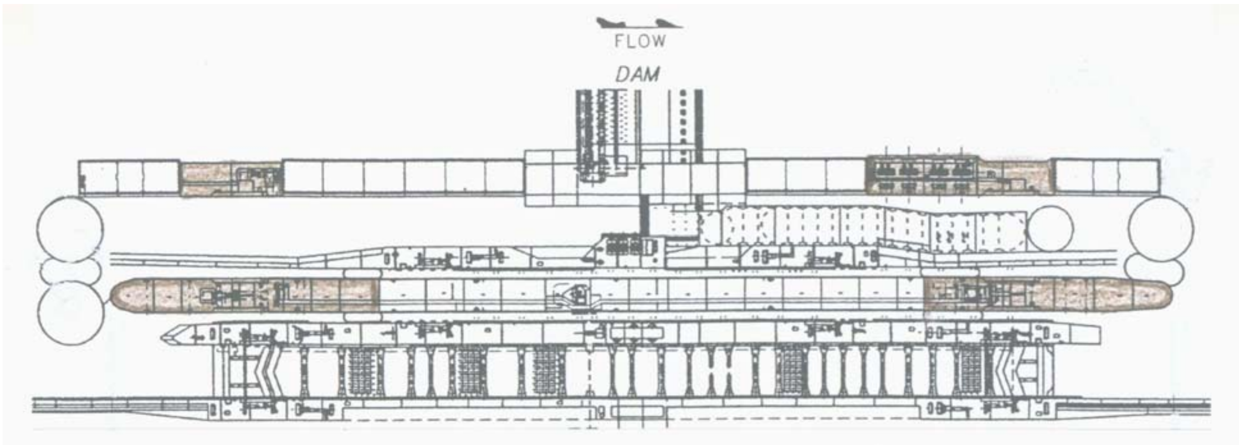


**Figure 4. Plan view of existing and new lock walls, with cofferbox monoliths shaded**

## Major Cofferbox Components

The cofferboxes will be composed of HZ king piles, AZ sheetpiling, internal bracing, and a tremie concrete seal, as shown in Figure 5. The HZ pile sections are rolled with special grips that mate with the AZ sections. Analysis indicates that a heavy combined wall section (HZ755D section) is required to provide the necessary section properties in order to minimize internal shoring requirements. In addition, the thickness of the piling must be sized to resist the cofferbox dewatering loads. The AZ section is an AZ18. The proposed spacing of the HZ sections is approximately 70 inches, on-center, for this arrangement.

The sheets will be driven a few feet below the top of rock surface, providing seepage control for the lock chambers. A test pile program was completed and determined that this depth of pile embedment is feasible. As shown in Figure 6, long rectangular cofferboxes will be constructed between two previously constructed monoliths, which will resist the longitudinal loads. In this way, longitudinal bracing is eliminated and constructibility is improved. The previously constructed monoliths will be completed using either smaller, approximately square cofferboxes or other construction methods.

The cofferbox internal bracing will consist of two levels of structural tube compression struts. The lower struts compression bolts will be tightened (by divers) against a lower internal waler, and the upper struts will be attached to an upper external waler. Vertical pipe posts are connected to the lower waler, both for installation and bracing purposes. The pipe posts and lower waler seats reduce the unbraced length associated with lateral torsional buckling considerations. Ease of component installation/removal and formwork placement was improved by locating the upper waler outside the cofferbox. The upper waler will also be positioned so that it can be constructed above the water, in-the-dry. Casings will be installed for construction of the drilled shaft monolith foundation. A thick layer of tremie concrete (typically 12 to 17 feet deep) will form a seal at the bottom of the cofferbox to facilitate cofferbox dewatering. This concrete will also support the drilled shafts, transferring loads between the shafts through compressive forces in the concrete, when the full monolith is subjected to lateral loads. The sheetpile will be anchored into the tremie concrete by WT sections, which will be welded to the sheetpile before driving.

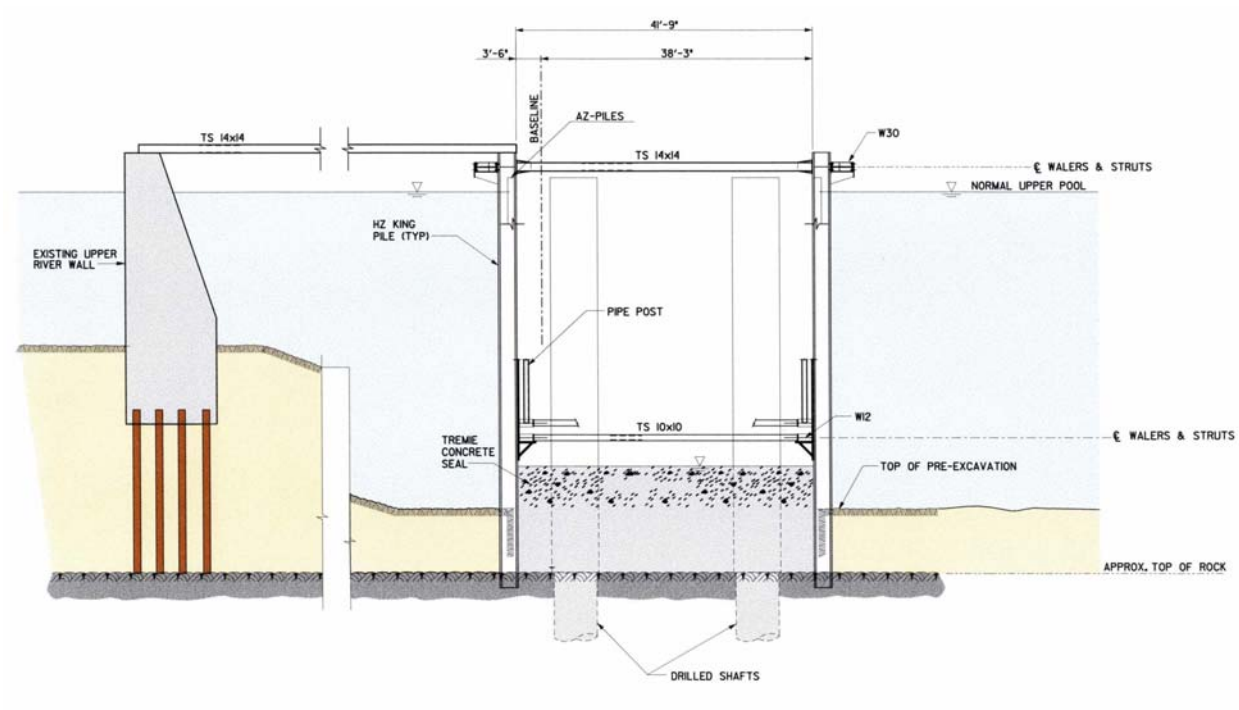


**Figure 5. Charleroi cofferbox cross section**

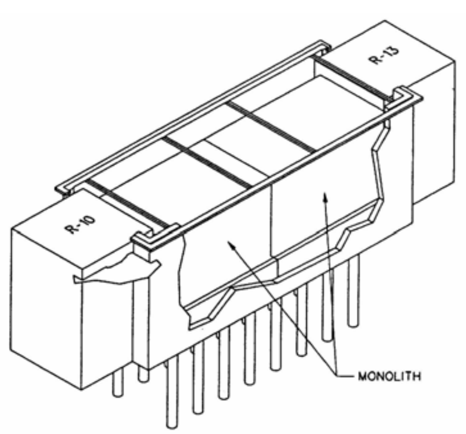


**Figure 6. Isometric view of a cofferbox between two previously constructed monoliths**

Partitions will be used to reduce the size of the tremie concrete placements. Larger tremie placements would require additional batch plant capacity. In general, a partition is placed at each monolith joint. Results from the nonlinear, incremental structural analysis (NISA) indicated potential cracking issues if the joints in the tremie are not aligned with the joints between the monoliths.

These tremie joints are achieved by placing a steel partition within the cofferbox at the required locations. The lateral loads from the tremie concrete are resisted by the drilled shafts adjacent to the partition. As shown in Figure 7, the partition is fabricated with two struts at each drilled shaft, which act as a guide to achieve the proper location, and tension hoops that pass around the drilled shaft and resist the concrete loads.

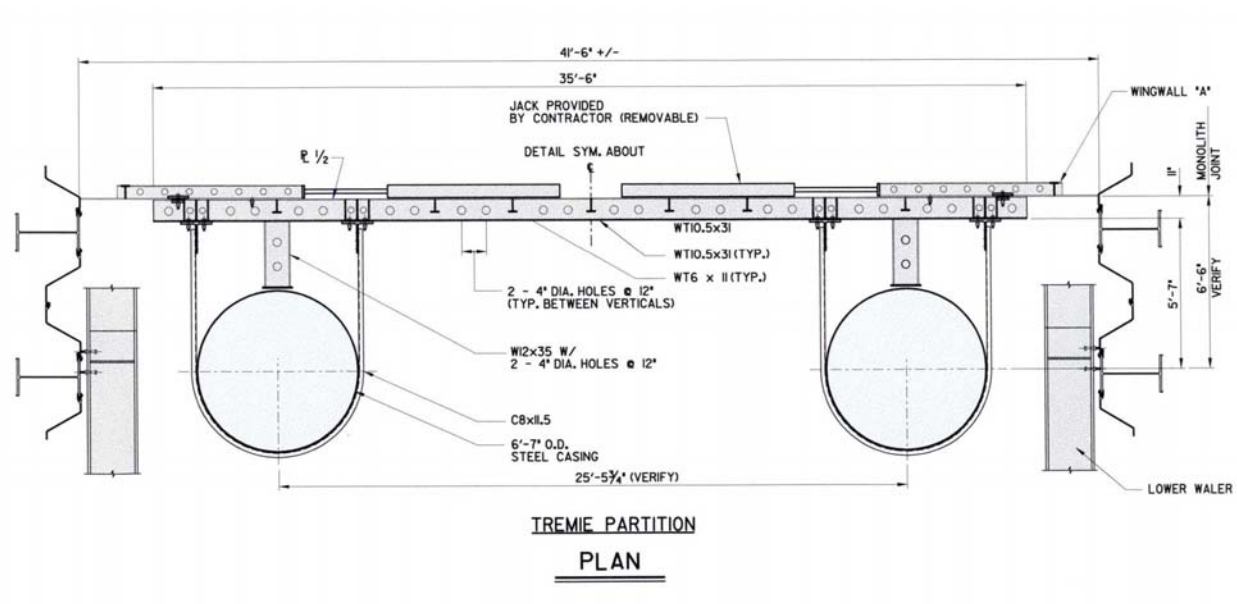


**Figure 7. Plan view of the cofferbox tremie concrete partition**

Since the partition must be lowered between the lower walers, it cannot be long enough to reach the sides of the cofferbox. To seal the space at either end, an adjustable panel was designed to slide outwards after the partition is in its approximate location. The panels can be operated by hydraulic cylinders (from above, in the dry), which move them outward until they contact the sides of the cofferbox. After the tremie concrete on one side of the partition is placed, the operating cylinders can be removed by divers and reused on other partitions. The partitions are used only as formwork for the tremie concrete. Other arrangements by the contractor may be approved, provided that they meet the requirements for joint locations.

## <u>Cofferbox Construction Sequence</u>

Prior to cofferbox and lock wall monolith construction, pre-excavation will be completed at the new river wall and new middle wall locations. This pre-excavation will leave a maximum depth of alluvium of approximately 9 feet and 21 feet at the new river wall and new middle wall, respectively.

After pre-excavation is complete, end monoliths will be constructed using either smaller, approximately square cofferboxes or other construction methods. Cofferbox walls will be constructed between these end monoliths, and drilled shaft casings will be installed within the cofferbox.

The lower shoring (lower internal waler and compression struts) will be lowered into position in-the-wet with the aid of divers, and the gap between the HZ piles and waler will be taken up by a system of bolts that will be set by a diver. The lower shoring is required to resist excavation loads before the tremie concrete is placed. It will be located a minimum of 4 feet above the tremie concrete elevation, so that it can be unloaded (by loosening the compression bolts) after the tremie concrete seal has cured sufficiently. Partial excavation inside the cofferboxes is not required before the lower shoring is placed, due to the pre-excavation described above. The lower level of shoring is also located at least 4 feet above the pre-excavation elevation. (For some cofferboxes, the lower strut elevation is governed by the top of tremie concrete elevation and, for others, the lower strut elevation is governed by the pre-excavation elevation.)

As mentioned earlier, the upper waler will be installed outside the cofferbox walls and above the anticipated pool elevation, so that it can be positioned and connected in-the-dry. In some cases, the top of the HZ piles will need to extend above the top of the AZ piling in order to facilitate construction in-the-dry. Upper struts will be installed, as required, within the cofferbox.

The shafts will be augered, reinforcing cages will be installed, and concrete will be placed within the casings, up to the top of the tremie concrete seal. In the case of the new river wall, access will be primarily from the riverside, so the drilled shaft construction is likely to be completed before the riverside cofferbox wall is installed but after the landside cofferbox wall has been completed. In the case of the new middle wall, a temporary work platform may be constructed on top of the cofferbox in order to improve access. If a temporary work platform is used, then the drilled shaft construction will be completed after the cofferbox walls and bracing have been fully installed.

After the cofferboxes (including associated shoring) and drilled shafts are constructed, the alluvium inside the cofferbox will be excavated and removed to the top of weathered rock. Tremie concrete will be placed at the bottom of the cofferbox, in one placement within the small cofferboxes and in multiple placements within the longer cofferboxes. After excavation but prior to tremie concrete placement, it will be important to clean the shaft casing and sheetpile surfaces well in order to achieve adequate bonding at these interfaces. The sheetpile/concrete interface is important due to seepage control considerations, and the casing/concrete interface is important due to adhesion requirements needed for load transfer of the net uplift force during cofferbox dewatering. The sheetpile recesses will be cleaned by jetting and then air-lifting the material. Similarly, the exterior casing surface can also be cleaned with water jets, lowering jet rings along the exposed height of the shaft casings.

After the tremie concrete has reached minimum strength requirements, the lower shoring will be unloaded (by loosening the compression bolts) and the cofferboxes will be dewatered. The cofferbox walls will resist the dewatering loads by spanning between the top of the tremie concrete and the upper walers and struts. In the dewatered cofferbox, the shaft casings will be cut flush with the top of the tremie concrete, and the lower compression struts will be removed. Monolith construction will continue, using conventional construction. As the top of the concrete lift approaches the bottom of the upper stuts, the cofferbox walls will be braced against the new monolith with short replacement struts, and the upper struts can be removed.

After monolith construction is complete, the sheetpile cofferbox will be cut off above the level of the tremie concrete. The bottom of the combined wall will remain seated in the top of rock for permanent seepage cutoff.

**<u>Contractor Input</u>**

In an effort to evaluate the constructability of the cofferbox designs, several contractors were consulted. Two contractors were contacted to discuss excavation within the cofferboxes. They both indicated that excavation within the cofferbox between the shaft casings and struts was feasible, reasonable, and less difficult than other more congested excavations, which they have completed. They also both indicated that they would prefer to complete this excavation after the casings are installed rather than excavate prior to casing installation. They said that they anticipated that the excavation will be completed using clamshell excavation and air-lifting. In addition, if the material can be dredged, then use of a dredge pump could greatly increase productivity, reducing the total construction time required. If large boulders are present, they will need to be removed with the clamshell.

A few contractors were contacted to discuss the minimum space required between the inside face of the cofferbox and the finished face of the concrete monolith. One contractor indicated that 2 feet would be sufficient, and the other contractor said that 3 feet would be required for formwork and personnel. Approximately 1 foot of this total space is required for the concrete formwork.

Based on this input, the distance between the inside face of the cofferbox sheetpiling and the finished face of the concrete monolith was set at 3'-6". Additional space is available for personnel in the recesses of the AZ sheetpiling. Walers do not encroach on this space, as the upper walers are installed on the outside of the cofferbox and the lower struts and walers can be removed prior to cofferbox dewatering and placement of conventional concrete formwork.

Two contractors were also asked about construction of the middle wall monoliths. When asked whether they would anticipate using a temporary work platform in addition to floating plants, both contractors said that they would expect to construct a temporary platform. One reason for the platform was the tight constraints associated with middle wall construction between the existing lock walls. A second benefit of work platform use was potentially reduced insurance costs for personnel. The third advantage of working from a temporary platform was the ability to work on multiple drilled shafts simultaneously, drilling a new shaft at the middle of the wall while the shaft concrete cured at the end of the wall. Without a platform, middle wall shafts associated with many of the Charleroi middle wall monoliths would have to be constructed sequentially, from the lower closure cell upstream, stopping to let the shaft concrete cure sufficiently in the current shaft before drilling the next shaft nearby.

## Construction Costs

Recent major increases in the demand for steel have increased the structural steel unit costs significantly. At the time of this writing, the project bids for the Charleroi Lock river wall construction are under evaluation, and the total lock and cofferbox construction costs are not fully known.

## Conclusion

A significant advantage of construction within local cofferboxes is the elimination of conventionally constructed cellular cofferdams. As a result, construction durations and costs are reduced and navigation impacts are minimized. Another advantage of local cofferbox construction is that, after the tremie concrete seal has cured and the cofferboxes are dewatered, the structure can be completed in the dry using monolithic concrete construction (which is particularly important for monoliths that are subjected to cyclic loading from miter gate anchorages). Similarly, use of other innovative designs for the new Charleroi Lock (such as a floating guard wall, a post-tensioned box beam guard wall, and slip-formed river wall monoliths) are anticipated to yield construction cost savings, reduced on-site construction time, and reduced impact on navigation traffic.