Designing of the Third Set of Locks

Greg Hillebrenner, *Vice-president MWH and Design Manager Panama Canal Expansion Third Set of Locks project*

As the Panama Canal celebrates its centenary in 2014, a new set of expanded locks is being built near the existing locks at the Atlantic and Pacific entrances of the canal. After 100 years of operation the condition and performance of the existing locks is still impressive and significant as they will continue to operate even after the completion of the new third set of locks (TSL). The newly designed TSL will allow for the passage of larger post-Panamax cargo ships that can carry approximately three times as many containers as the existing Panamax ships can when traversing the canal.

The new locks have been designed by a joint venture (JV) led by MWH Global (US) that also includes TetraTech (US) and Iv Groep (Netherlands). The JV, contracted to design-build contractor Grupo Unidos por Canal (GUPC), has designed a new set of locks that have applied many of the lessons of the first canal in order to build a new set of locks that will address the needs of the Canal for the next 100 years.

A layout for the next 100 years

Both the existing and new Atlantic and Pacific locks move ships between the ocean and Gatun Lake and back to the ocean in three nearly equal steps at each end of the canal, a total vertical distance of approximately 26m. This is accomplished using the principals of gravity, with no pumping of water

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Top: Rendering of the Third Set of Locks project from the Pacific entrance. Joint venture design led by MWH Global (US) and including TetraTech (US) and Iv Groep (Netherlands); Right: Rendering of TSL Atlantic side showing lock gates in the closed position.

involved, controlled by a sequence of hydraulically-operated valves that convey water from Gatun Lake through the lock chambers to the ocean.

Availability of the locks for passage of ships is extremely important and critical to the success of such a large and heavily-trafficked canal. To accomplish this reliability, the current locks use two parallel lanes near each ocean entrance. In addition to providing for an efficient movement of more ships, this arrangement also provides a redundancy to the system that allows maintenance to be performed on one set of chambers while allowing the other set to be fully operational.

For the new set of locks the owner, Panama Canal Authority (ACP), decided on a single-lane layout to reduce construction costs and also to avoid having to construct additional water sources to support the operation of the canal system with the new locks. The TSL chambers are approximately 50% wider and longer than the existing locks and are built to accommodate post-Panamax ships. The current locks consist of two parallel sets of three chambers, each 33.5m wide by 305m long, whereas the TSL's single set of three chambers are each 55m wide by 427m long. And to accommodate a greater draft for the larger ships, the chamber wall heights have been increased to 33.5m from the current 26m.

The single-lane design requires that the TSL have built-in redundant features to allow minimal downtime for maintenance. The TSL scheme has been designed to ensure continuous availability for 99.6% of the time. Achieving such high levels of reliability necessitated a detailed evaluation of all equipment and maintenance requirements, as well as ensuring that a robust, proactive maintenance schedule was in place.

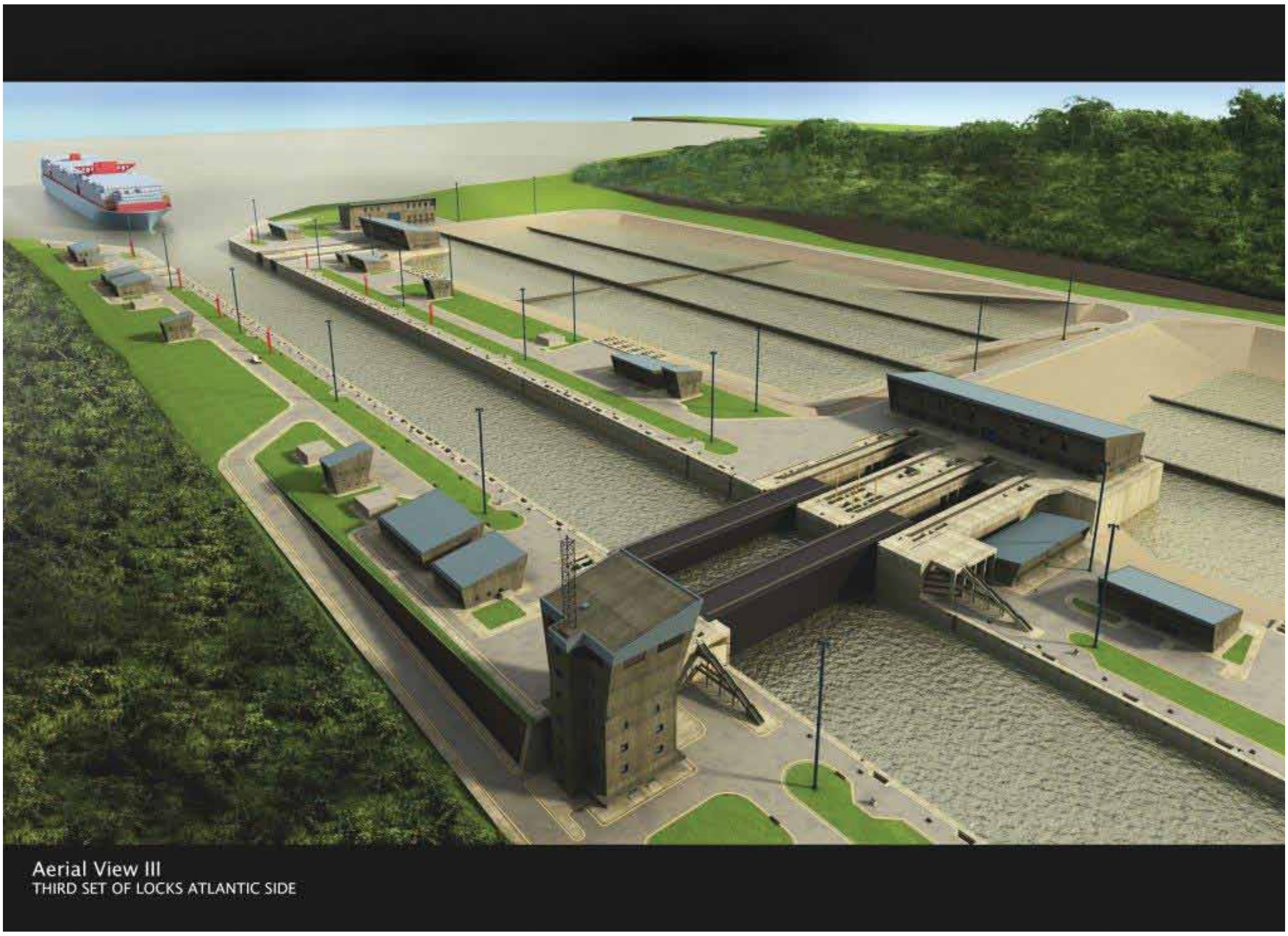
One important redundant feature implemented for the TSL is having two identical rolling gates at the ends of each TSL lock chamber. Each gate can be completely retracted into a recess in the concrete structure; once closure panels are put in place, the recess can be dewatered to allow maintenance on one gate, under dry conditions, without interrupting the operations of the TSL

Additional redundancy would be provided by future construction of a fourth set of locks – as envisaged by ACP – that would allow for temporary maintenance shutdowns of the TSL and potentially accommodate the passage of even larger ships.

Conserving water

The source of water for both the existing and new lock systems is Lake Gatun, created by Gatun Dam located at the Atlantic entrance of the canal. When designing the TSL, the team had to make the most efficient use of available water within the Lake Gatun watershed so as not to require the construction of an additional source, such as a new dam and reservoir. To avoid such an eventuality, ACP opted to incorporate Water-Saving Basins (WSB) into the design of the TSL project. Comprised essentially of a local water-storage reservoir for each chamber, covering an area of approximately 10ha, the WSB is subdivided into three smaller sub-basins at different operational levels.

Utilising wheel gate-type valves to control flow in both directions for filling and emptying the lock chambers, the gravity operation of the WSBs allows for nearly 60% of the water required for each lockage to be reused. This allows the TSL to use approximately 7% less water for a total lockage than



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The new steel lock gates are 30m high, 58m long, between 8-10m wide and weigh up to 4,400 tons.

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Preparing to place the gates into position, August 2014.

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The two recesses into which the sliding gates are retracted for opening/closing operations and for maintenance.

the existing locks, even though the new chamber size is much larger. The net quantity of water used for a complete transit (ie, both Atlantic and Pacific lockages) and discharged to the ocean is reduced to 180 million litres (equivalent to approximately 70 Olympic-sized swimming pools) for the TSL when the WSBs are used, as compared to 200 million litres for the existing locks without WSBs. The TSL can also be operated without using the WSBs during maintenance periods or when the water level in Lake Gatun reaches too high a level during the rainy season and ACP desires to release additional water to the ocean to lower the lake level.

Choosing a lock gate

The current locks use a traditional mitre gate, which was the standard type of gate used for lock structures at the time the existing locks were constructed. The existing locks contain two mitre gate leafs at each location, weighing up to 700 metric tonnes each, that must either be removed by a large floating crane or have the lock chamber dewatered to allow in-situ maintenance in the dry.

ACP undertook a thorough evaluation of the types of gate to be used on TSL, given its wider lock chambers and the increased need for redundancy and performance of maintenance activities. Following extensive research into locks globally, ACP decided to incorporate rolling lock gates into the TSL, as opposed to the mitre type used on the existing locks.

Given the stringent 99.6% reliability requirements for the TSL, combined with a wider and deeper chamber, and increased seismic and fatigue criteria, ACP decided to use rolling gates operated by a motorised drive mechanism, each of which can be opened or closed in 4–5 minutes. There are a total of eight new gates at each lock complex, two at each of the four lock heads (for redundancy) that form the three lock chambers.

These new, enormous steel gates are on average around 30m high by 58m long. Depending on their location and due to different loading conditions, the gates have a width of 8m–10m and weigh 3,000–4,000 metric tonnes. Integral flotation chambers and the effects of buoyancy mean that the operating weights of the mostly submerged gates are around 10% of their gross dead weight, or 330-440 metric tonnes. The 16 new lock gates have been fabricated by Cimolai in Italy and are being shipped to Panama in groups of four aboard a ship specially designed to safely transport the large gates across the Atlantic Ocean. On reaching Panama, half of the gate total will then be transported individually by barge through the existing locks and canal to the Pacific site.

Tug boats replace locomotives

During the planning process for the project, ACP made a decision to use tug boats instead of locomotives, as used for the current locks, to guide ships through the new lock chambers. This decision was made for both economical and practical reasons – too many locomotives would have been required to guide the larger post-Panamax ships. In addition, locomotives over the decades of use have proven to be costly to both purchase and maintain.

To assist the tugs, post-Panamax ships are required to be fitted with special bow thrusters. The TSL chambers will also have continuous rubber fenders installed along their walls to protect the ships and walls from damage.

Aerial view of Atlantic site, August 2014


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Aerial view of the construction at the Pacific site, August 2014.

An efficient filling and emptying system

In the existing lock chambers, water is introduced and evacuated via a bottom-filling/emptying system comprised of 100 round openings in the floor of each chamber. But the new TSL filling and emptying system utilises side-filling – a series of 20 port openings (each measuring 2m by 2m) are located at the base of the lock walls along each side of a chamber. Water is supplied to these ports through a secondary culvert supplied with water from the WSB (60% of total) and an interconnection to the main culvert connected to Lake Gatun (40% of total). This new system can fill or empty each chamber in 17 minutes when using the WSB and 10 minutes without using the WSB.

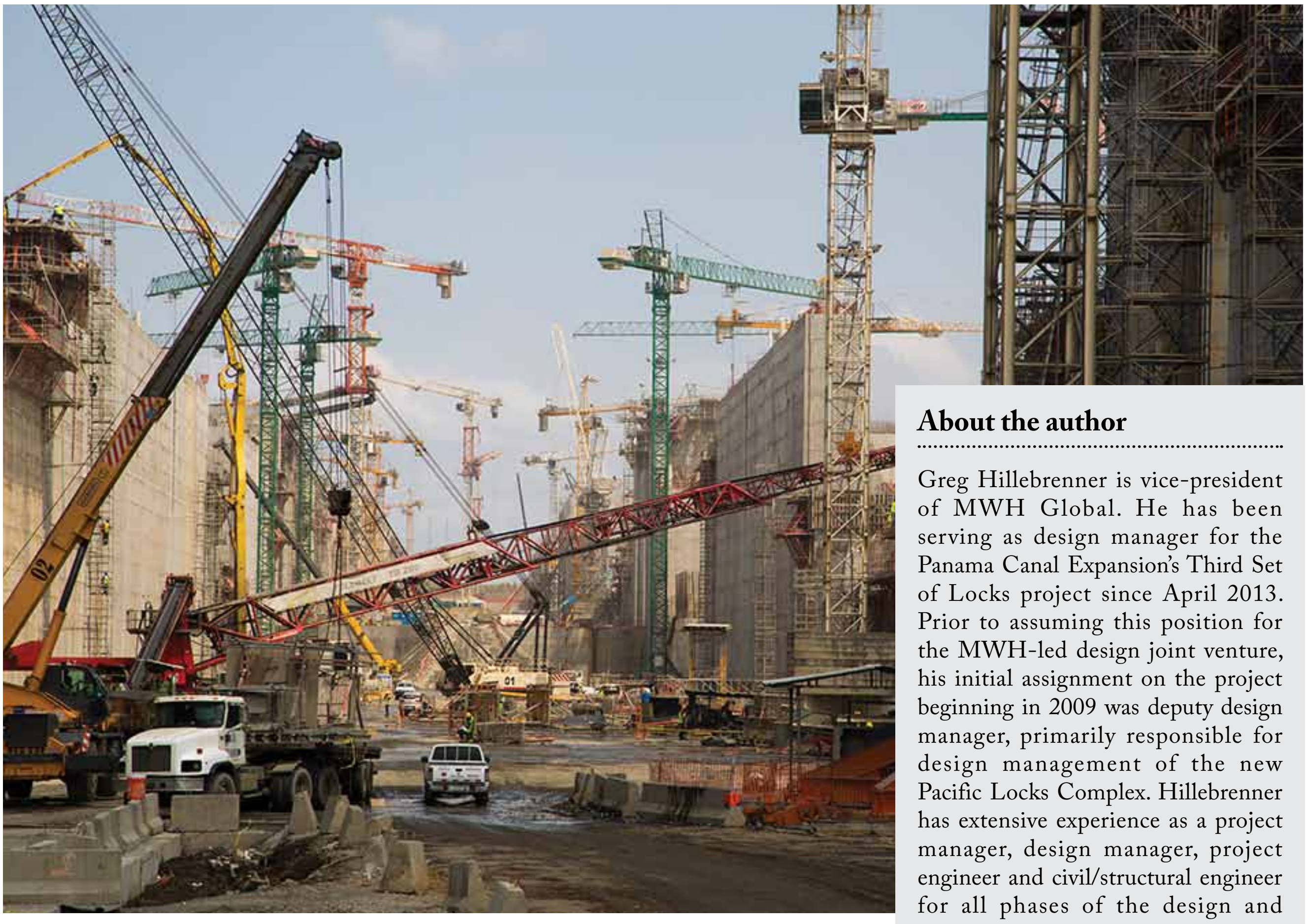
First time seismic criteria

Not much was known about seismicity across the Isthmus of Panama during the design and construction of the existing locks. Studies for the new TSL in 2004 determined that there existed a potentially significant seismic risk for the project and, therefore, stringent design criteria for seismicity should be included in the designs for the new locks. While the there are no active faults in the direct vicinity of the Atlantic site, the Pacific site required special design for four faults that crossed the project – three for Borinquen Dams and one for the TSL Upper Chamber. Higher seismic requirements for the new locks involve resisting large, lateral earthquake design forces that require the use of reinforced concrete, as opposed to the mass concrete used in the existing lock system. Due to the different seismic risks determined for the Atlantic and Pacific sites, the new Pacific Locks Complex concrete structures require approximately 30% more reinforcement steel than the Atlantic Locks Complex. A total of nearly 220,000 tons of concrete reinforcement steel for the TSL project is required, as compared to the unreinforced mass concrete used for the existing locks.

Concrete requirements

When determining the criteria for the new locks design, ACP placed a stringent requirement that all concrete should have a service life of 100 years; it should also withstand the variability of water salinity, ranging from fresh water to high-salinity seawater, and also the resulting corrosion of any steel reinforcement in the concrete. These were not factors for the existing locks, which were constructed using mass concrete without reinforcement.

Water salinity in the lock chambers varies across the project – it is lowest at the freshwater intake from Lake Gatun, and highest at the ocean entrances of the canal. To provide an economical design with reduced potential for cracking, while also providing the required corrosion protection for reinforcement, a 60cm-thick structural marine concrete mix that is more dense was used as an outer 'skin' for the lock structures. This denser mix was used to encapsulate the reinforcement in areas exposed to contact with water and to surround an interior mass concrete mix that contained a lower cement content to reduce heat generation. Multiple concrete mix designs were developed by the contractor for the structural marine concrete to accommodate the variable salinities of the water that exist throughout the length of the lock chambers. Sophisticated thermal analyses were performed to determine the required maximum placement temperatures needed to reduce the potential for cracking due to the large temperature gradients and excessive drying shrinkage. Lower placement temperatures for the



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A very busy construction site.

concrete were achieved by introducing ice water at the batch plant during the mixing process.

Impacts of previous excavations

Between 1939 and 1941, the United States began excavations for a new set of locks; however, with the onset of World War II, construction was put on hold and later abandoned after the war ended. These previous excavations at each site significantly affected the design and construction of the TSL, but in different ways. At the Atlantic site, the previous excavations benefited the project, as it was possible to align the TSL chambers within the existing excavation. This allowed the new chambers to be excavated by widening and deepening the previous excavations to accommodate the larger dimension required for the TSL.

At the Pacific site, however, the opposite situation existed and the previous excavations negatively affected the project expansion. Due to physical space limitations at the site, it was not possible to locate the chambers for the TSL within the existing excavations. Not only was it necessary to excavate completely new lock chambers , it was also required to remove the water and soft muck that had accumulated in the previous 30m-deep excavation and backfill it with rock and earth fill to the ground surface to allow construction of the WSBs, operations buildings and access roadways. Once the project is complete, however, the TSL Complexes at each site will appear nearly identical.

Summary

It is difficult to describe in such a short article all the similarities and differences between the existing and new locks. However, the author hopes the reader has been given a useful insight into the design and construction of this immense feat of engineering. For 100 years, the existing locks have proved durable and have performed beyond expectations, thereby setting the benchmark to be met or exceeded by the new TSL. As the tools available for analysis and design have become much more sophisticated since the original design, so have the expectations and requirements for a service life of at least 100 years. This requirement, combined with the reliability factor of 99.6%, has pushed the design envelope to a new level, such that the Panama Canal Expansion's new TSL sets new standards for the future design of navigation locks throughout the world.

About the author

Greg Hillebrenner is vice-president of MWH Global. He has been serving as design manager for the Panama Canal Expansion's Third Set of Locks project since April 2013. Prior to assuming this position for the MWH-led design joint venture, his initial assignment on the project beginning in 2009 was deputy design manager, primarily responsible for design management of the new Pacific Locks Complex. Hillebrenner has extensive experience as a project manager, design manager, project engineer and civil/structural engineer for all phases of the design and construction of large water resource projects. He has a Bachelor of Science degree in civil and structural engineering from the University of Illinois at Champaign-Urbana.

About the organisation

MWH Global is the premier solutions provider focused on water and natural resources for built infrastructure and the environment. Offering a full range of innovative, award-winning services from initial planning through construction and asset management, MWH partners with clients in multiple industries. Its nearly 8,000 employees in 35 countries spanning six continents are dedicated to fulfilling its purpose of 'Building a Better World', reflecting its commitment to sustainable development. MWH is a private, employee-owned firm with a rich legacy beginning in 1820.

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