Chapter 1

The New Panama Canal

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Additional information is available at the end of the chapter

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Abstract

The canal of Panama is one of the most emblematic constructions in the world, for that reason, for Sacyr, the construction of the Third Set of Locks has been a great challenge and huge pride. The chapter details the technical specifications and innovative breakthroughs that have been used in the work. Detailing the hydraulic filling and drainage system, gate system, control systems, and auxiliary systems. The final result shows the innovation capacity of the technicians who have participated in this work, who have been one of the keys to be able to overcome the challenge that Sacyr committed to Panama and the rest of the world.

Keywords: canal, panama, locks, innovation

1. Introduction

The Panama Canal is one of the most emblematic works of construction in the history of the humanity. For this reason, for Sacyr, to lead the consortium responsible for the construction of its most representative and complex feature, the Third Set of Locks, is a matter of enormous satisfaction and great pride.

Sacyr's broad experience and success in the field of construction and services speaks for itself: today, the company is listed on the IBEX 35, the blue chip stock index of the Spanish stock market.

Founded in 1986, Sacyr's commitment to work quality and customer satisfaction, along with its determination to grow, has been the keys to its success. Sacyr is now a diversified company with a presence in more than 20 countries on 5 continents through its subsidiaries [1].

Sacyr maintains the "GLOBAL INNOVATION" motto, the result of which is that it currently has the hallmark of "Excellence in Innovation" in its gold form, certified by Germany's TÜV Rheinland group.

On the other hand, in R&D activities, SACYR has approved and works under an R&D Management System certified by AENOR since 2006. In the last 10 years, we have 14 companies of the Sacyr group certified in R&D, among them all participated in 193 projects with national and international external recognition, adding among all these projects a total budget in R+D+i activities amounting to €220, 593, and 332.

The Panama adventure began in the middle of the international financial crisis. Nonetheless, Sacyr structured a technically and economically solid proposal and reached agreements with key partners that allowed it, at the last moment and in a fully sobering investment climate, to win the concession of the most important public works program of this century. The construction project of the Third Set of Locks has acted as an absolute reinforcement of Sacyr's management and determination to remain in the forefront of the sector [**5**].

The Panama Canal has had an undeniable success in international transport logistics since it has allowed the transit of more than 700,000 ships since its inauguration in the 1914. As a consequence of this success and with the need to expand their capacity, Panamanian citizens decided in the referendum of October 22, 2006, to construct the Third Set of Locks of the Panama Canal. This decision has involved an investment of more than US$5250 million and aims to capture the estimated demand until beyond 2025 building a Third Set of Locks with capacity to double the tons that in total transit annually through the channel. In this way, and considering the diversity of possible ships, total annual traffic could approach 20,000 vessels.

The dimensions of the chambers of the new locks were established on the basis of those of the vessels Neopanamax, with a length of 366 m, a sleeve of 49 m, and a maximum draft of 15 m. EastDesign vessel was considered as the target capacity and routine use size in trade routes. Its maximum capacity is 14,500 TEUs (unit equivalent to a container 20 ft long, 8 ft wide, and 8.5 ft high), 3 times capacity of the largest admissible vessels to date, the Panamax, which with 294 m of length, 32 m of sleeve, and 12 m of draft, can transport 4500 TEUs. The dimensions of the new locks may also receive vessels of solid bulk and liquid type Capesize and Suezmax, respectively, with loading capacities in excess of 160,000 dwt (tons of Deadweight), LPG and LNG gas transport vessels with volumes exceeding 135,000 m^3, Cruisers, and car carriers with transport capacity of more than 8500 vehicles.

The new set of locks has required the excavation of the corresponding approach channels from both oceans. On the Pacific side, 6.1 km has been excavated as an approach channel, parallel to Lake Miraflores, to connect with the waterway upstream of the locks of Pedro Miguel. In addition, it has been necessary to deepen and widen the internal channels of Culebra Cut on the Pacific side and Gatun Lake in the Atlantic, together with the 45 cm increase in the maximum operational level in Gatun Lake. **Figure 1** shows a plan view of the expanded Panama Canal with the actions that has been necessary to undertake.

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1.1. Remarks

1. Deepening and widening of the access channel in the Pacific and Atlantic.
2. Deepening and widening of the internal canal in Culebra Cut and construction of the new bypass channel of Pedro Miguel.
3. Construction of the new locks and water saving basins (WSB) (Atlantic-Pacific).
4. Deepening and widening of the internal navigation channel to Lake Gatún.

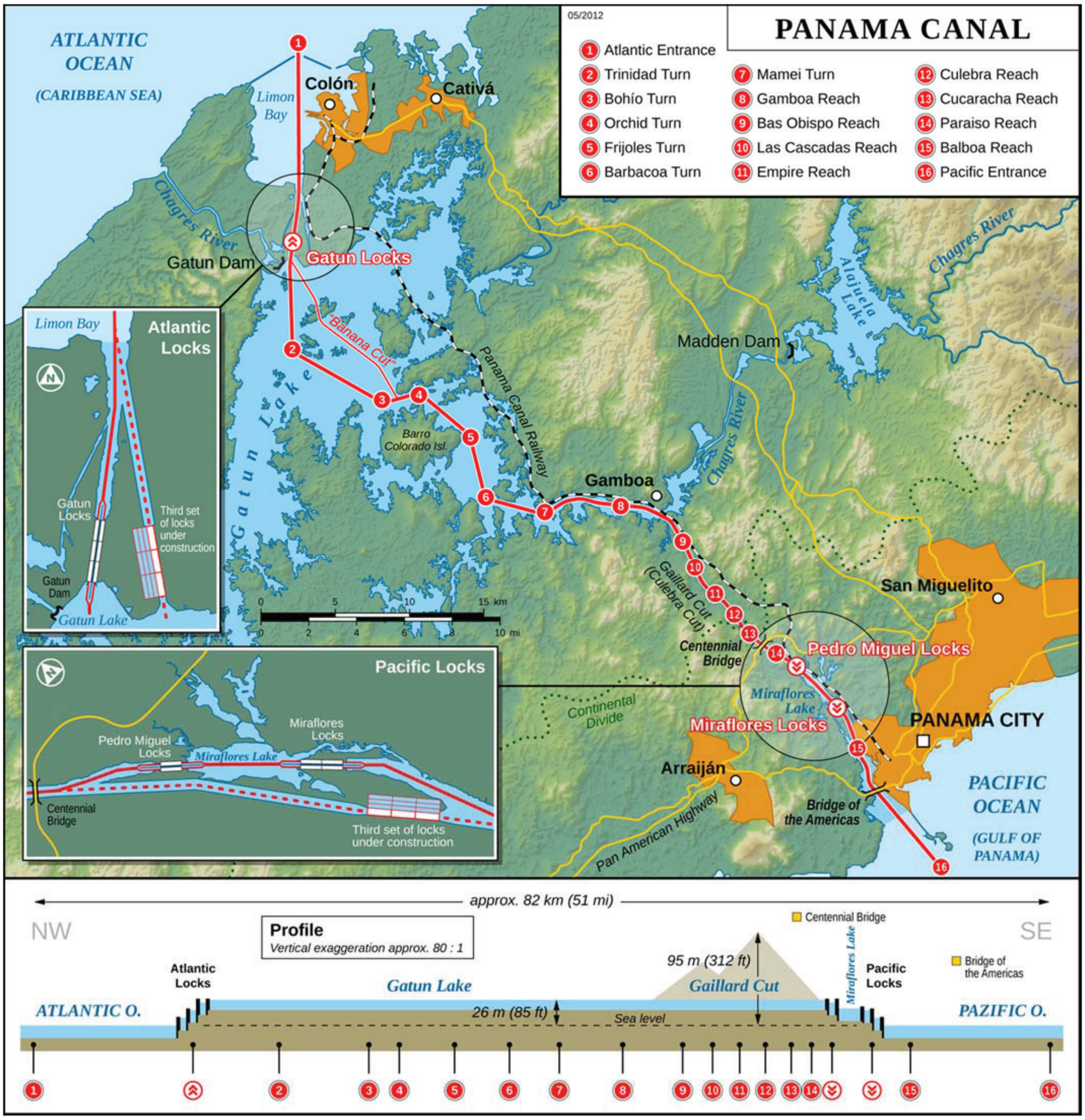

Figure 1. General map of the Panama Canal and its enlargement. Below, longitudinal cut of the navigable route.

The bidding process for the Third Set of Locks began on December 21, 2007 with the issuance of the request for proposals by the Panama Canal Authority (ACP) for the project. On July 15, 2009, these works were awarded to the consortium Grupo Unidos por el Canal (GUPC), which obtained the best technical and economic score (base budget of US$3119 million), with Sacyr being the leader company of the Consortium.

2. Description of the Third Set of Locks

The original locking system was based on the concept of creating an elevated artificial lake (present Lake Gatun) with a depth that would allow the ships to cross Panama from ocean to ocean and the construction of locks at each end of the way to allow the descent of the ships from the lake to the ocean or vice versa, ascending from the ocean to the lake. The operations of ascent or descent of the ship are obtained by the movement by gravity of the water coming from the lake and accumulated annually in the periods of rain that registers Panama.

The original locks of the Panama Canal have two parallel lanes, called games, which allow both sides of the road both on the Pacific side and on the Atlantic side (**Figure 1**). The general functioning of the Third Set of Locks is similar to that built by France and the United States 100 years ago, although it has significant differences in the equipment used. Like the original system, the Third Set of Locks saves the approximately 27 m gap between the zero bound of the Atlantic and Pacific oceans and the level of Gatun Lake. To do this, it uses three jumps of about 9 m each, communicated by gates. The complex of locks of the Pacific side has been called Cocolí and the one of Atlantic Clara Water, following the name of the rivers in each zone. Unlike the mitering of the original gates, the new gates are rolling, being collected in concrete side niches. All the essential elements of the Third Set of Locks are duplicated, ensuring the operation of the system even during the failure of any of them so that there are eight floodgates in each complex, four couples on the Atlantic coast, and four couples in the Pacific [**6**].

The filling and emptying of the chambers is done through a system of galleries—main and secondary ducts—operated by valves and operating completely by gravity. These galleries run longitudinally along the sidewalls of concrete and communicate with the chambers by ducts arranged horizontally at the height of the hearth, unlike the original channel, in which the entrance of water to the chambers is realized vertically in the hearth. The Third Set of Locks also has a complementary water reuse system. This system consists of a battery of water saving basins (WSB) arranged in parallel to the chambers, which are capable of reusing up to 60% of the water required in a complete locking manoeuvre. Each chamber has three basins, arranged in three levels, which are emptied and filled by gravity and are also managed by valves.

It should also be noted that the original Panama Canal has a unique vessel positioning system. A set of towing locomotives guides the boats from the locks to the locks, allowing them to move in the fully centered chambers. In the new channel, tugs are used inside the cameras to achieve the same objective.

The works of the expansion were concentrated in an area of 2300 m by 350 m where the three chambers that house two gates at each of its ends and the pools of water saving are located, as shown in the **Figures 2** and **3**.

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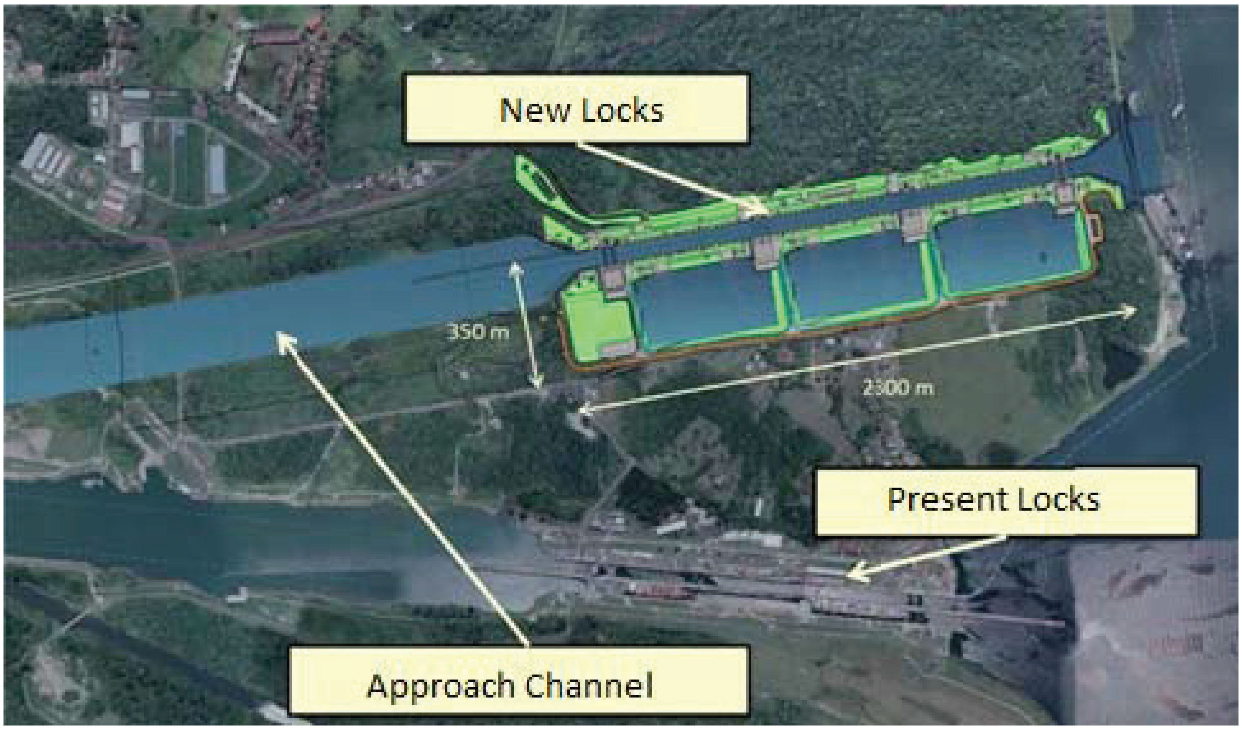

Figure 2. Overview of the project.

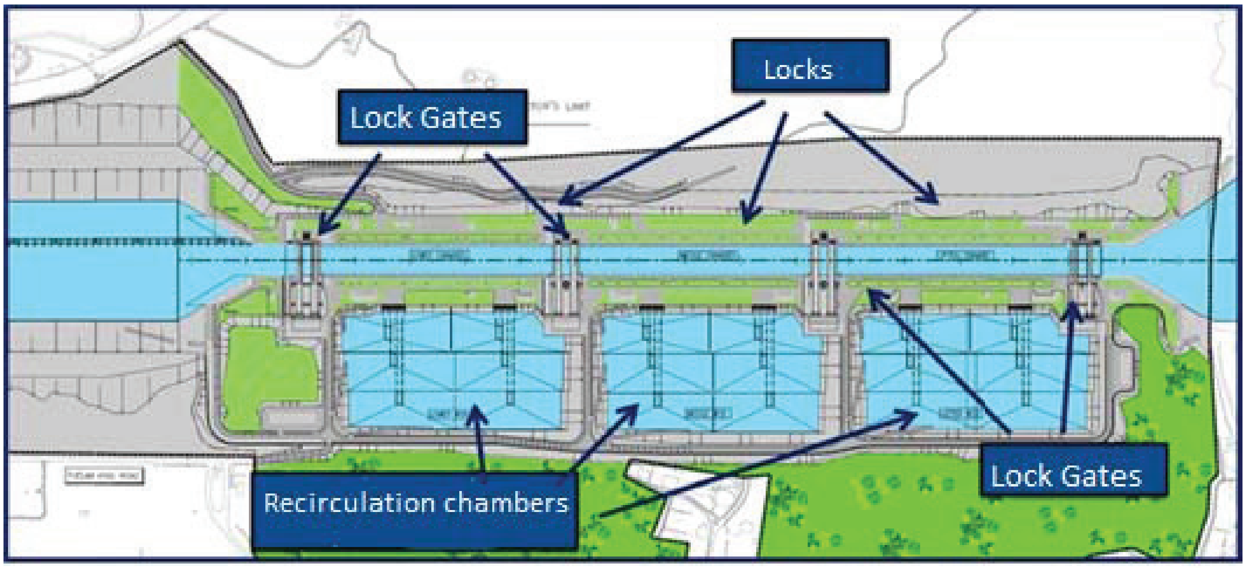

Figure 3. Main elements of the project (Atlantic side).

Apart from the locks, the Atlantic side also includes canal approach dredging and the north-east approach structure, whose function is to orient the ship and align it at the entrance to the first lock. This approach dock has a length of 500 m and has been built in pile—board type prefabricating the beams in the same work. On the Pacific side, the access channel has also been dredged and two approach structures have been arranged, one at each end of the locks, built using the same typology as in the Atlantic sector.

Current chanel overview [2]	
Canal length	77 km
Gap between oceans and lake	27 m (Although variable according to the tides and lake water level)
Dimensions of the chambers	304.8 × 33.5 × 12.8 m
Characteristics of the largest vessels allowed	289.6 × 32.3 × 12 m
Volume of water discharged by locks	96,300 m^3
Current share of world maritime trade (without expansion)	5%
Capacity annual tons in transit (without expansion)	330 millions of tons CP/SUAB
Annual transits	Almost 14,000
General information on the Third Set of Locks	
Duration of works	6 years
Maintenance period included in Contract	3 years
Volume of construction work	112 million man hours
Volume of design works	3 million man hours
Operating manuals delivered to ACP	300 manuals
Civil work	
Excavation volume (structures and quarries)	68 millions m^3
Volume of landfills (structures, dams, and landfills)	50 millions m^3
Structural concrete volume	5 millions m^3
Volume of dredged material	6 millions m^3
Arming steel weight	269,000 tons
Borinquen dams of loose materials	Nearly 3 km of total length, 37 m of height, and 30 m of width of the upper berm.
Primary crushing plant capacity	3300 tons/h (Pacific)
Capacity of secondary and tertiary crushing plants	1300 tons/h (Pacific and Atlantic)
Performance achieved in the manufacture of concrete	540 m^3/h
Performance achieved in concrete pouring on site	5000 m^3 daily
Transit tip trucks on the Pacific side	2000 daily trucks
Buildings (96 units)	47,000 m^2
Electromechanical systems	
Total number of valves	158
Total weight of steel in valves and their accessories	20,000 tons
Average throughput during locking	550 m^3/s
Total number of gates	16
Total weight of steel in gates	51,000 tons

Dimensions of the largest gate	57.6 × 10 × 33.04 m
Steel weight of the largest gate	3900 tons
Total number of medium voltage cabins (12 kV)	32
Power installed in transformation for each complex	26 MVA In each of the two redundant rings
Installed capacity in batteries for critical loads (4 h)	20,000 Ah
Total length of installed electrical cables	2000 km
Total length of Fiber Optic cables installed	400 km
Management of the control system for each complex	100,000 signals 34 servers 74 work stations 500 PLC
New locks in service	
Reliability (% operating time)	99.6%
Maximum capacity with basins	15 vessels/day
Maximum capacity without basins	17–18 vessels/day
Capacity of annual tons in transit	300 millions of tons CP-SUAB
Unloaded water volume with basins	90,000 m^3/lockage
Unloaded water volume without basins	230,000 m^3/lockage
Dimensions of the chambers	427 × 55 × 18.3 m
Characteristics of the largest vessels allowed	Neopanamax (12,500 TEUs, 366 × 49 × 15.2 m)
Concrete design life	100 years
Design life of the gates	50 years
Human factor	
Number of workers	40,000 people
Proceedings	79 Different nationalities
Beneficiaries of training courses	21,800 people
Peak period workers	14,000 people
Work team in January 2016	790 People expatriate staff 931 people Panamanian staff 3460 workers
ACP operators trained by the contractor for the operation and maintenance of the Project	160 people
Environment	
Number of rescued animals	More than 4.500
Reforested area	2.800 ha
Number of trees planted	5.8 millions
Estimated CO_2 balance by reduction of transits	160 millions CO_2 yearly

Table 1. Significant magnitudes of the project.

Table 1 summarizes the most significant magnitudes of the executed project.

As comparisons with familiar elements, we could expand the table above with the following information:

The locks are 427 m long, equivalent to four football fields.

For the expansion of the Panama Canal, 220,000 tons of steel have been used, equivalent to 22 Eiffel Towers.

In addition, 2100 km of wiring have been used, the distance between Miami and New York.

3. Hydraulic filling and emptying system

The hydraulic system of the new locks differs from the original canal in two main elements: The Borinquen dam, which communicates the set of locks on the Pacific side, as detailed in the introduction, and the implementation of Water Saving Basins, WSB. This solution allows to handle ships with 2–3 times more load, but using 7% less water than the original channel [**4**].

The new locks should be understood in their conception, like a great hydraulic machine conceived to pass enormous volumes of water in few minutes. The design of the filling and emptying system required studies with supercomputers and physical models to ensure compliance with the requirements of the contract. In fact, the challenges were not only limited to the time needed to balance the adjacent chambers, but also their durability (vibration control, cavitation, and air intake) and safety (the water surface must be kept as horizontal as possible to avoid excessive movements in the vessels that generate high efforts in their moorings). Let us see in detail how the system works and the challenges we face will become evident.

The locks work thanks to the principle of communicating vessels. Each chamber is a water container that, with the use of valves, communicates with the adjacent one. In this way, the water of the chamber at higher height goes down to the one of smaller height until they reach the same elevation. The water is never pumped up, the water always goes down from one chamber to the next by gravity. If the boat is in the chamber to be emptied, it will go down along with the water level. If it is in the one that is more empty, then it will rise. This is the theory, now it has to be put into practice. If we limit ourselves to the three chambers, without taking into account the WSB, this communication is done with the valves of the main ducts ("Culvert Valves").

The main hydraulic lines communicate with the three chambers, passing under the gates in the area of the garages (**Figure 4**). They are located inside the boxes of the chambers of the Third Set of Locks that are formed by concrete walls. The tellers are monoliths built in reinforced concrete of high resistance, low permeability, and high durability (100 years). The walls of the chambers present two types of concrete, one in mass that solidifies the core of the monoliths (Internal Mass Concrete), and another structural, of high resistance to marine means and very low permeability (Structural Marine Concrete) that covers all the surface of the structure. The walls have an approximate height of 30 m on foundations and a width in

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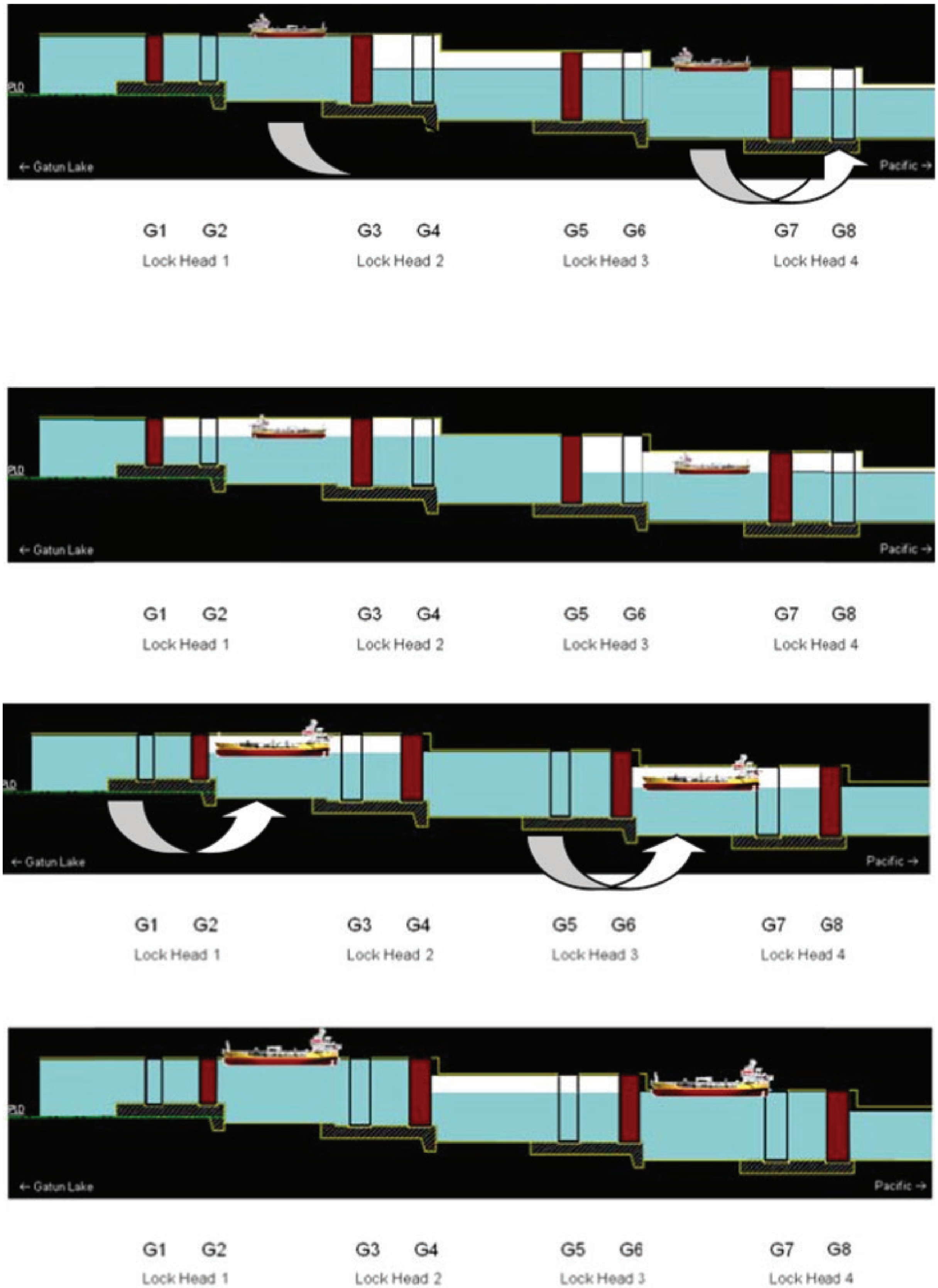

Figure 4. Principle of operation of the cameras as communicating vessels.

the base of about 27 m. Its triangular profile resembles that of a dam, but in this case, they have a prominent core at the base, which houses the hydraulic conductors, as indicated above. The back of the wall is in contact with a selected soil filling until crowning. **Figure 6** shows a cross-section of said wall with the mentioned hydraulic lines.

During this operation, the water used does not depend on the size of the boat, since the volume required depends on the area of the chambers and the difference in level between the two. If the area of the chambers cannot be modified, the level difference can be reduced by using the water saving basins (WSB). These chambers are not very different from the main ones, but placed at intermediate elevations allow us to reduce the water expense. Each time the level of a camera is lowered, the lateral tubs are used, filling their three levels in a decreasing way. Whenever it is necessary to refill the chamber, it will communicate with the three water saving tubs in increasing order and these will return the necessary water. Before the ship can pass, a final equalization between camera and camera will be executed, but at much more similar hydraulic levels and with much lower water expenditure. This manoeuvre will have saved 60% of the water needed for the locking (**Figures 5–7**).

We could say that the system of filling and emptying is the channel of Panama, the pulsating heart of the work. The efforts dedicated to the development of this system were immense. If something had not worked as expected, very little could have been done to solve it. However, this system is extremely particular. The amount of water handled in each operation is unrivalled in the world, and the time available for each extremely short operation. The main elements are similar to other channels with recovery tanks, but none brings to the limit the existing technology as the Third Set of Locks. Grupo Unidos por el Canal and all the companies involved soon realized that what was learned in similar applications here was not enough.

Numerical models and physical models were of vital importance to the success of the project. Each solution was investigated in a simplified 1D model, then entered data into 3D models at specific points. The level of detail and the complexity of the phenomenon, prevent the models from analyzing the flow throughout the system (**Figure 8**). Available supercomputers

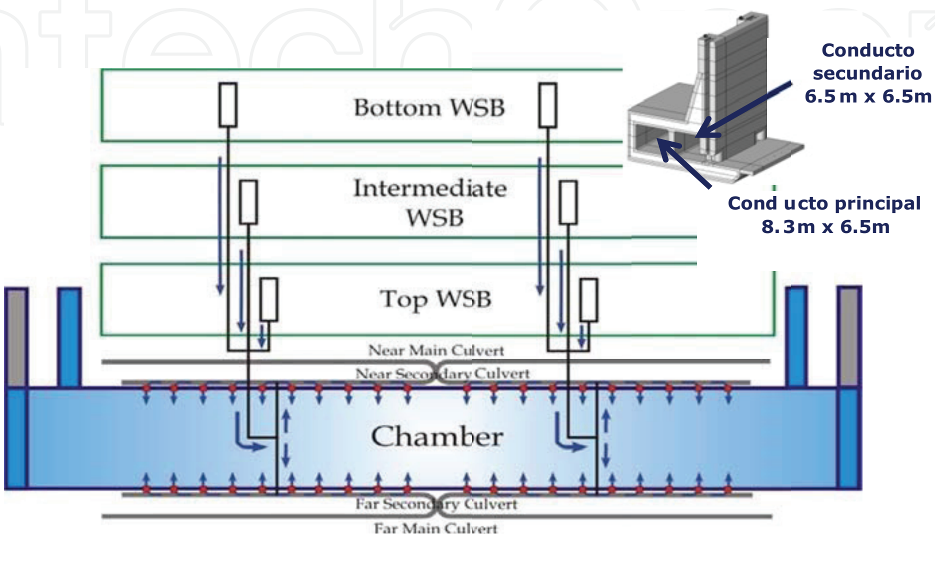

Figure 5. Bottom view of the main conduits (culvert) and water saving basins (WSB).

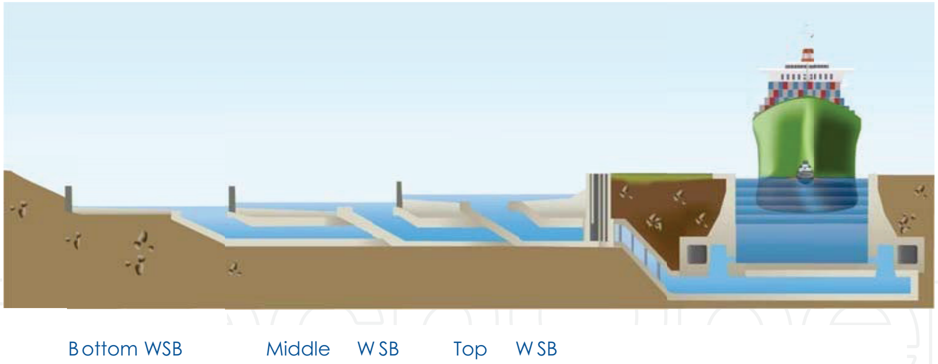

Figure 6. Cross-section of the water saving basins (WSB).

Figure 7. Aerial image of the water saving basins (WSB).

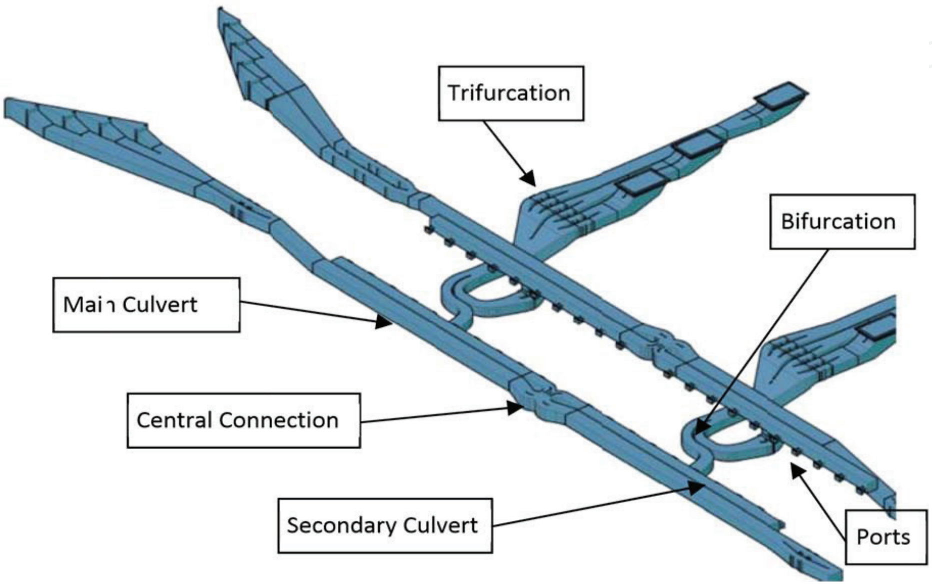

Figure 8. Schematic representation of the ducts in the upper chamber.

took days in solving the equations describing the flow of water. Obviously, each solution was tested in a physical model built in Lyon (France) in scale 1/30. The model was a lock in itself. This model not only allowed to validate hydraulic solutions well before the construction, but also to estimate effects very difficult to assess with numerical methods, such as the currents of salinity that form in the ocean or the influence of the approach structure in this flow. The physical model was monitored with more than 100 sensors providing data on water levels, velocities, pressures, differences in elevation in the chamber, and forces exerted on the vessel during the locking process and optimum position of the valves. The correlations obtained between the physical and numerical models were very high, so that the distribution of flows in each critical section of the model was very well controlled.

4. System of gates

The gates of the Third Set of Locks are of the "sliding" type. They are moved using an upper carriage and a lower carriage with wheels on rails located in said zones (**Figure 9**).

This type of gate has several advantages over the hinged doors of the original channel. One of them is the use of the niche where they are located in open position like dry dock to give maintenance to the floodgate without having impact in the operations.

Figure 9. Overview of a gate in operation.

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Figure 10. Overview of the structure where the two gates are located at each end of the chamber.

Each lock has three chambers so that the jump of approximately 27 m from the sea to the lake is divided into three steps of 9 m each (**Figure 10**). This requires four of these structures located at the end of each chamber, space in which each pair of gates is placed. The gates go in pairs precisely for reasons of redundancy and maintenance. If one of the two is in the niche and cannot be used, then the sister allows the operations to continue without problems. There are also safety reasons and, for this reason, when the ship is in motion there are always two gates closed to the front.

The entrance from either of the two oceans finds its first pair of gates—the 7 and the 8—at the beginning of the first camera, the inferior one—Power Chamber. These gates make the system independent of the oceanic tide races, very pronounced in the Pacific, where they reach 6 m of difference, and more moderate in Atlantic, with 1 m of unevenness approximately. The next pair of gates—5 and 6—is about 9 m above the previous ones, at the beginning of the chambers—Middle Chambers. The third pair—3 and 4—identical to the previous ones, is at the beginning of the upper chamber—Upper Chamber, which rises again about 9 m from the intermediate one. The last pair of gates—1 and 2—separates the Gatun Lake locks system, whose water level under ordinary conditions is about 27 m above the reference level of both oceans.

The gates present different dimensions and weights depending on the contour conditions that determine their buoyancy. In effect, the gates are orthogonal parallelepipeds, which have hollow and watertight chambers, arranged in each case at the necessary height and with the precise dimensions to reduce dead weights and allow their buoyancy. These watertight chambers work like the hull of a boat, reducing the operating weight of the gates up to 85% of their dry weight to be able to slide them. In this way, the total vertical force that the gates of the gates must support does not exceed 600 tons in total.

The manufacturing and transport operations of the floodgates have been, due to their complexity and spectacularity, one of the images that more media monitoring has had in the execution of this work. For these operations, the use of self-propelled heavy cargo transport trolleys (SPMT), barges with dozens of pumps capable of compensating the transfer of cargo and with two ocean-going heavy cargo ships adapted to the present project (**Figure 11**).

Each gate is supported by two wagons. One moves along the niche in the concrete structure, in the highest part, and by this is defined as upper wagon. This car is responsible for transmitting the movement to the gate through a beam where the pulleys are located, as we will see later. At the other end of the gate, the carriage is located in the lower part of the gate and rolls on a rail placed at the bottom of the chamber (**Figure 12**). To facilitate its maintenance, the connection point between the lower wagon and the gate is located at the top of the gate, outside the water, and the gate is supported by a column. This eliminates the need for complicated dives in the channel for the extraction of the wagon provided every 5 years.

In the case of the Panama Canal, the watertightness and durability requirements are extremely demanding. The seals have to guarantee a leak of less than 5 L/min/m and a life of 15 years or 135,000 cycles, operating more than 20 times a day. Almost all floodgates of this type in the world work with the tides, 2–4 times a day. A fairly common solution is a wooden support with a thickness of plastic mounted on the gate and a support of smooth concrete or natural stone in which it is supported and sealed. This solution could not guarantee the required benefits and it was necessary to analyze other alternatives. The one that was finally adopted consists of a rubber stamp in the

Figure 11. Unloading of the gates on the quay side Atlantic.

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Figure 12. Conceptual diagram of the operation of the gates.

form of a musical note ("J-seal"), independent of other functions, that activates with the hydraulic differential and is deactivated when the equilibrium is reached. This solution is more common in valves of dams or dry docks. Several tests were necessary to ensure that the rigidity of the profile was correct. A too rigid profile would not be activated in time, while too soft one could be activated with differences in water levels sufficient to move the damper, with the risk of damaging it.

5. Control system

The power control system (PCS) is designed to operate safely, reliably, and functionally the Third Set of Locks. It is divided into two major sub-systems:

1. The lock machinery control system (LMCS): This system is in charge of operating, monitoring and controlling valves, gates, and auxiliary systems.
2. The electrical distribution control system (EDCS): This system is in charge of operating, monitoring and controlling the control centers of motors, transformers, direct current equipment, and other electrical equipment.

The control system was designed in order that the lock could be operated in the most reliable, safe, and easy way for the lock operator. Today, a single operator in each lock is able to operate the control system to achieve the passage of ships through the channel.

There are three operating consoles in both locks, which are distributed as follows: two consoles are located in the control tower (CB) and a console is located in the back-up building (BCB) of the lock. The operator can operate in any of the three existing consoles, which were designed in order to have a redundant system, either within the same control tower or inside the backup building in case something happened to the tower of control.

6. Auxiliary systems

The auxiliary systems correspond to those complementary functions necessary for the operation of the Third Set of Locks, such as the systems necessary to guarantee the physical security of the Canal, to manage the traffic in an efficient and safe way above the floodgates, to detect and to extinguish a Fire or monitor the area with thermal cameras.

7. Conclusions

The expansion of the Canal has been cataloged in several publications as the most important work of recent years worldwide. There is no doubt that the strategic importance of the Panama Canal and its original epic construction, with all the difficulties suffered by Ferdinand de Lesseps in the first instance and the American government in its final stage, have influenced this consideration. However, there are other elements that have contributed to the media interest aroused throughout the planet during its construction. Among these technical elements are the enormous volumes of work, the dimensions of the floodgates, the water-saving pools, and the singularity of the project itself, which are discussed below:

7.1. The volumes of work

In the previous chapters, we have detailed the magnitudes that make the new Canal an enormous work. These volumes require a special logistics both for procurement and for execution of work. The small industrial fabric present in Panama complicates much more this logistics. Detailed planning has therefore been necessary to resolve this point.

7.2. The dimensions of the gates

The 16 steel gates have focused the technical interest of the work during its final phase. The transport of these 16 structures has been complex, not only because of its weight (almost 4000 tons in the worst case) but also because of its size (58 m in length, 10 m in width, and 33 m in height). The equipment and experience in transport processes and installation of heavy load have been carried to their maximum capacity.

7.3. Water saving basins

The main engine of the channel as we have already mentioned is the water coming from the rain. One of the requirements of the project was to save water used in the operation of the Canal. The side pools of water saving have been an innovative measure that has worked perfectly and has managed to reuse on average 60% of the water used in each lock.

7.4. The singularity of the project

The new locks have undoubtedly been a unique project that has required the development of unprecedented solutions; Prototypes never used previously. It is here that innovation has played a key role in the technical success of the project. Among the innovations of the most significant electromechanical elements, we must highlight those relating to materials and construction procedures and also those that refer directly to the execution. In the dosing of concrete, it has also been necessary to implement innovative measures that have already been the subject of technical articles in this regard, as discussed below:

7.5. Innovations in materials and construction procedures

The locks, as well as other hydraulic works, combine two technologies that are constructed in a different way: the part of civil work with concrete implementation with centimetric precisions and mechanics that require millimetric precisions. In the installation of valves (guide rails) and gates (guiding, support, and sealing elements), it has been necessary to solve complex problems in order to make civil works and mechanical elements compatible. The final solution has been given through the installation of adjusting elements (embedded in first and second stages of concreting) and the selection of materials, such as high density polyethylene which enabled the machining in the shop or *in situ* to achieve precisions of the order of magnitude of 1 mm.

In parallel, the specifications of the ACP reference document included compliance with water leakage values through the seals of the unusual gates, in this type of infrastructure. Solutions known for that point of contact using stainless steel, polished stone, special woods, or other materials used in similar locks in Holland or Belgium were not suitable. That is why GUPC together with its designers and subcontractors began an investigation to develop a solution that combined a rubber seal with steel sheets on prestressed panels of high-density polyethylene. After several tests at the CIMOLAI facilities, the University of Udine (Italy), the 1:1 test facilities at MARIN (The Netherlands), fatigue tests at several European laboratories and on-site adjustment tests, the expected result, and meeting customer requirements.

The functionality of the auxiliary systems described above has also required the use of the most innovative equipment on the market, sometimes requiring a tailor-made adaptation for the application in the Panama Canal.

7.6. Innovations in execution

It is difficult to segregate those aspects that have stood out for their innovation in the constructive process. The points mentioned above, work volumes, transport, and installation of floodgates, have in themselves generated the need to implement unusual sequences and procedures on site. There is, however, a characteristic of this work that makes it unique in front of many others: it combines a civil work of great volumes with elements of an industrial work also of great magnitude and of high complexity. For example, during the commissioning phase, more than 200 calibration locks have been carried out, requiring more than 33 million m^3 of water, more than 2000 integration tests of the different systems present and should be carried out under supervision of ACP the 14 tests with 36 different hydraulic scenarios to verify the requirements of the project. These activities were carried out while the rest of civil, mechanical, electrical, and control activities were completed. This simultaneity of activities can only be managed through proper preparation (planning) and with a practical and effective control system.

The first point regarding the execution of the start-up phase was overcome with detailed and detailed planning. This process was prepared for over a year and a half. The thousands of planned activities were analyzed to finally elaborate a sequence that allowed adjustments according to the degree of progress of the work and the unforeseen that could appear. With the procedure already developed, the start-up sequence could be completed in 7 months, reducing in almost 2 months the initially planned time.

The second point was related to the control system that would allow overlapping of the hundreds of simultaneous and concurrent activities in the same space that were given on a daily basis. It required a simple methodology that would ensure the possibility of progressing on all these fronts but minimizing the possibility of accidents. If there is simultaneous electrical work, testing of mobile equipment and civil activities (painting, concreting, and finishing in buildings) by program requirement, the risk of accident increased significantly. The solution was the implementation of a system of work permits by zones, controlled by LO-TO procedure ("Lockout-tagout"), and supervised by a team of dispatchers. This system, although habitual in works in industrial plants, has been novel in a work of thousands of people with simultaneity of activities of so many different disciplines [3].

7.7. Final reflexion

As a final conclusion to highlight that the ability to innovate of the technicians who have participated in this work has been one of the keys to be able to overcome the challenge that SACYR committed to Panama and the rest of the world.

The acquired know-how must allow to face works of great importance and of high technical complexity in which the Spanish companies are in the international avant-garde (**Figure 13**).

Figure 13. Passing of the ship Cosco Shipping Panama with 10,000 TEUs during the inauguration of last June 26, 2016.

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