HOW TO POWER NAVIGATION LOCKS WITH ELECTRICITY

by

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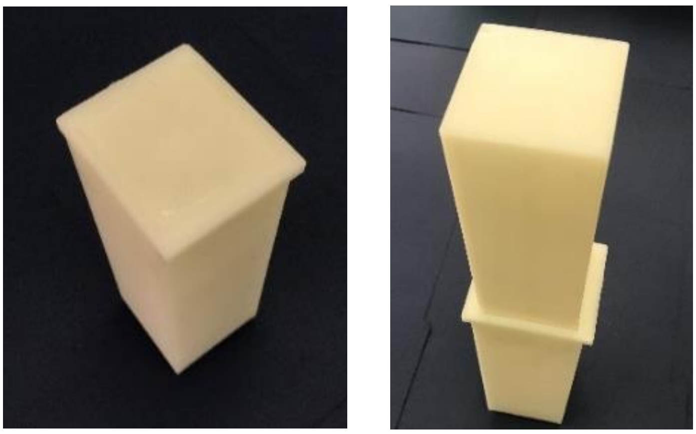
1. WHY WE NEED AN “AIR LIFT LOCK” DEVICE?

The need to power navigation locks with electricity is simply being able to operate the locks when hydropower is not available. This technology is developed considering Panama’s need for more revenues from the Canal and population’s need for more potable water. Panama’s water resources, primarily from Lake Gatun, are abundant but several droughts made the population aware of its limits. The record for most annual transits was set in 1971, 14,500 transits or nearly 40 transits per day. This number of transits is essentially the limit to Canal operations set by the availability of hydropower. The Panama Canal Authority has increased its revenues by increasing the size, not the number, of ships that transit the Canal daily. The Neo Panamax Locks increased the average ship size and revenues but has not increase the total number of transits. In 2017, the total transits were 13,549 or 37 transits per day.

The technology to power navigation locks with electricity will allow Panama to exploit its principal resource, it’s geographic location, to its full potential without the limit imposed by the availability of water. It will eliminate draft restrictions on shipping through the Canal during droughts, and it will guarantee the population potable water without compromising canal operations. This technology is developed in Panama because water conservation has become one of our country’s greater needs.

2. DESCRIPTION OF DEVICE

The device that powers navigation locks with electricity is described first, for the clarity of further explanations. The intent is to incorporate this technology first as a retrofit to the Panamax Locks. Therefore, the device presented here as the “Lock Air Lift” is designed specifically for this purpose. Figure 1 is a photograph of a physical model, scale 1/60, of the device. The device is shown, both in its closed and open positions. The device consists of two shells that slide in a telescoping manner to form a parallelepiped. The parallelepiped has a square top and bottom, 3.50 m wide, top and bottom surface and rectangular sides 11.00 meters high. The device is made of steel, and is powered by a hydraulic piston, 60 cm in diameter located along the centerline. The top of the device is flush with the lock floor, it expands vertically 8.6 meters met in a telescoping manner. The vertical expansion of the device corresponds to the level the water needs to rise in the lock chamber.



a) closed **b) opened**

Figure 1: Physical Model of Lock Air Lift Device, Scale 1/60. a) closed, b opened

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The Panamax locks present suitable conditions for the introduction of this technology:

- The Panamax Locks have two lanes, so one lane can be shut down for the installation of the device while the other lane allows the locks to operate at a reduced capacity.
- These locks are not currently used to their maximum capacity of 45 ships per day. Their current use, 30 ships per day, is set by the availability of hydropower for canal operations.
- The device can be installed without compromising the lock's hydraulic culverts providing the locks a dual energy system.
- The author's experience as construction supervisor on "Overhauls" of the Panamax Locks provides a reference to the design proposals herein presented.

3. A THERMODYNAMIC SYSTEM FOR THE PANAMA CANAL

The Canal will be considered as a Thermodynamic system to envision the addition of another source of energy to power the operation of the Panamax Locks. The amount of energy required to lift one ship through one step of a Panamax Lock is shown in equation 1.

$$E=m^*\left(H+\frac{\Delta H}{2}\right) \tag{1}$$

Where:

E: energy, kg-m (kWh)

m: mass, kg

H: height of water, m

ΔH: increase in height, m

$$E=33.54^*304.88^*15.24^*1000^*\left(15.24+\frac{\Delta 8.61}{2}\right)=5{,}420{,}869\ \text{kg-m}\ (14.77\ \text{kWh})$$

For reference, the cost of this energy would be $1500, if this energy were electricity. The expenses of using electricity are calculated at the rate of $0.10-kilowatt hour. However, this modest energy requirement is coupled to a huge power requirement. The time stipulated to raise the water level in the lock chamber is 15 minutes. The power is calculated by equation 2. This huge power requirement precludes the use of water pumps to recirculate the water in the locks. The device that powers the locks with electricity must meet this power requirement.

$$P=\frac{E}{t} \tag{2}$$

Where:

P: power, kW

t: time, h

$$P=\frac{14.77\ kWh}{0.25h}=59\ kW$$

Figure 2 depicts the Canal as a Thermodynamic System. The total amount of energy available per year to the Canal and how it is expended is shown. The energy, hydropower, can be described in terms of the volume of water, at the elevation of Gatun Lake, as Mm3. The energy calculated for one lock step is multiplied by three, corresponding to the three steps from ocean to lake of the Panama Canal locks, to obtain the energy of one transit. The Neo Panamax Locks consume 7% less than the Panamax Locks because of the water savings basins.

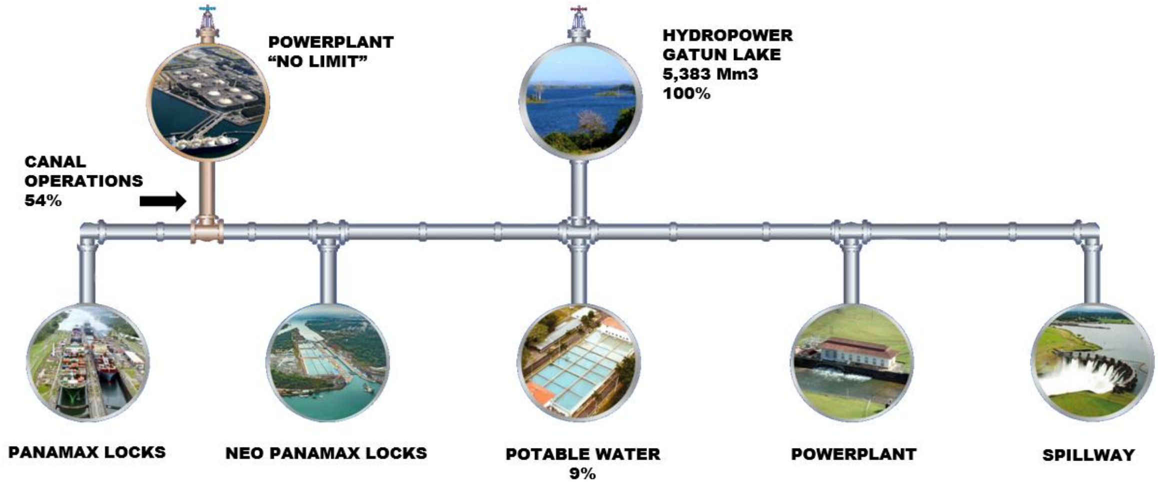

Figure 2: The Panama Canal as a Thermodynamic System

The total available hydropower in Gatun Lake, is 5,383 Mm3. The principal use of the hydropower of Gatun Lake is to power the canal's operations, 2,897 Mm3 (54%). Gatun Lake is also the population's principal source of potable water, it consumes 485 Mm3 (9%). A large part of the total energy cannot be used, 1,991 Mm3 (37%), this water is used to generate electricity at the Gatun Power Plant or is spilled at Gatun Spillway, because of the limited storage capacity of Gatun Lake and the limited spilling capacity of Gatun Dam.

The energy is sold by the Panama Canal Authority at vastly different prices. For comparison, the unit price of the energy at each distribution point follows - at the Neo Panamax Locks, up to $1,200,000 per transit ($447,000 average), at the Panamax Locks up to $400,000 per transit ($121,000 average), for municipal consumption, $40,000 per transit and at the Gatun Power Plant $1,500 per transit. One transit consumes 196,841 m3 of water. Note that the value of water for electrical generation is the theoretical value of the energy needed to lift the ships, as corresponds when the energy loss is minor. The revenues at each distribution point cannot respond to market demand because of the limit imposed by the availability of water.

The opportunity to increase the fresh water resource to the Canal is limited. The current proposal for a new dam and reservoir at Rio Indio would only increase the available energy a fractional increment where the introduction of a new energy source could increase the available energy without any limits. Although providing water for the population's consumption is not profitable when compared to the Panama Canal's operations, this activity is of great priority. The population's growth rate has required the construction of additional potable water plants on Gatun Lake. This increasing demand for water compromises the efficiency of the Panama Canal's operations. It also puts in jeopardy the revenues to the government that it must increase.

4. THEORETICAL BASIS FOR OPERATION

The operation of the device is based on three fundamental principles: the first law of thermodynamics, Archimedes' principle and Pascal's principle. These principles are well known.

The idea that electricity can power navigation locks is validated conceptually by the first law of thermodynamics - energy cannot be created or destroyed, it can only be transformed. The purpose of this device is to transform electricity into hydropower. The energy of hydropower is simply the water's potential energy as defined by its elevation. Devices that transform one form of energy to another have changed history, most notable is the steam engine which started the industrial revolution.

Archimedes' principal validates that the water level in the open vessel of the lock chamber can be raised by placing a solid at the bottom of the vessel. The placement of the solid at the floor of the locks is the function of the device. The solid emerges from the floor of the lock chamber as the result of the expansion of the device. The solid displaces the water and the water level rises within the enclosed vessel of chamber. The flotation line on the ship remains constant, so the ship rises as the water level rises. The rate of emergence of the solid is less than the rate at which the flotation level rises such that the device never encounters the ship bottom. For the level of water in the chamber to rise the amount needed to transit the ship without adding any water would require full coverage of the floor with these devices. Think of these devices as tiles on a floor, the more of the floor that is covered with tiles the less water needs to be added to operate the locks. Figure 3 depicts an idealized cross section of a navigation lock chamber where the water level is raised with this device.

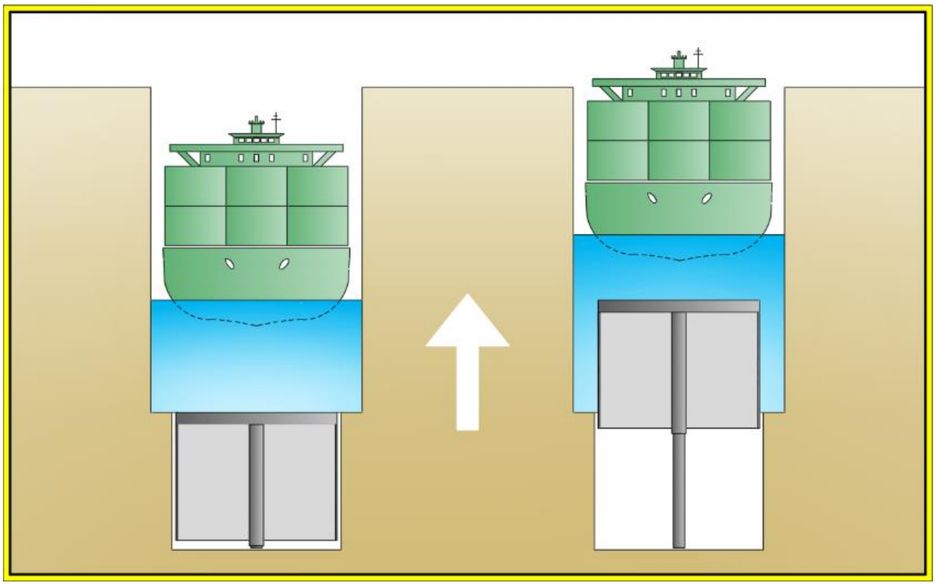

Figure 3: Operation of Device

As stated earlier, although the energy requirement to lift the ship in the lock chamber is moderate, the power requirement is huge. The expansion of the device is achieved with hydraulic power. The center of the device is a hydraulic cylinder / piston. The hydraulic fluid within the cylinder is at high pressure to achieve high forces. Pascal's principle is the basis for hydraulic power technology. Hydraulic power systems are also powered by electrical pumps. The volume of hydraulic fluid required to operate the device, compared to the volume of water needed to fill the lock is reduced proportionally, up to100 times, by the ratio of the hydraulic pressure to the ambient pressure. The reduced volume transfer requirement of the hydraulic power system compared to recycling the water with pumps, makes them practical.

5. DESIGN OF THE DEVICE

The device and its operation has been described. The design of the device has been advanced so that the components can be sized and their cost estimated. The device has two main components, the steel shells with the telescoping mechanism, and the hydraulic power circuit.

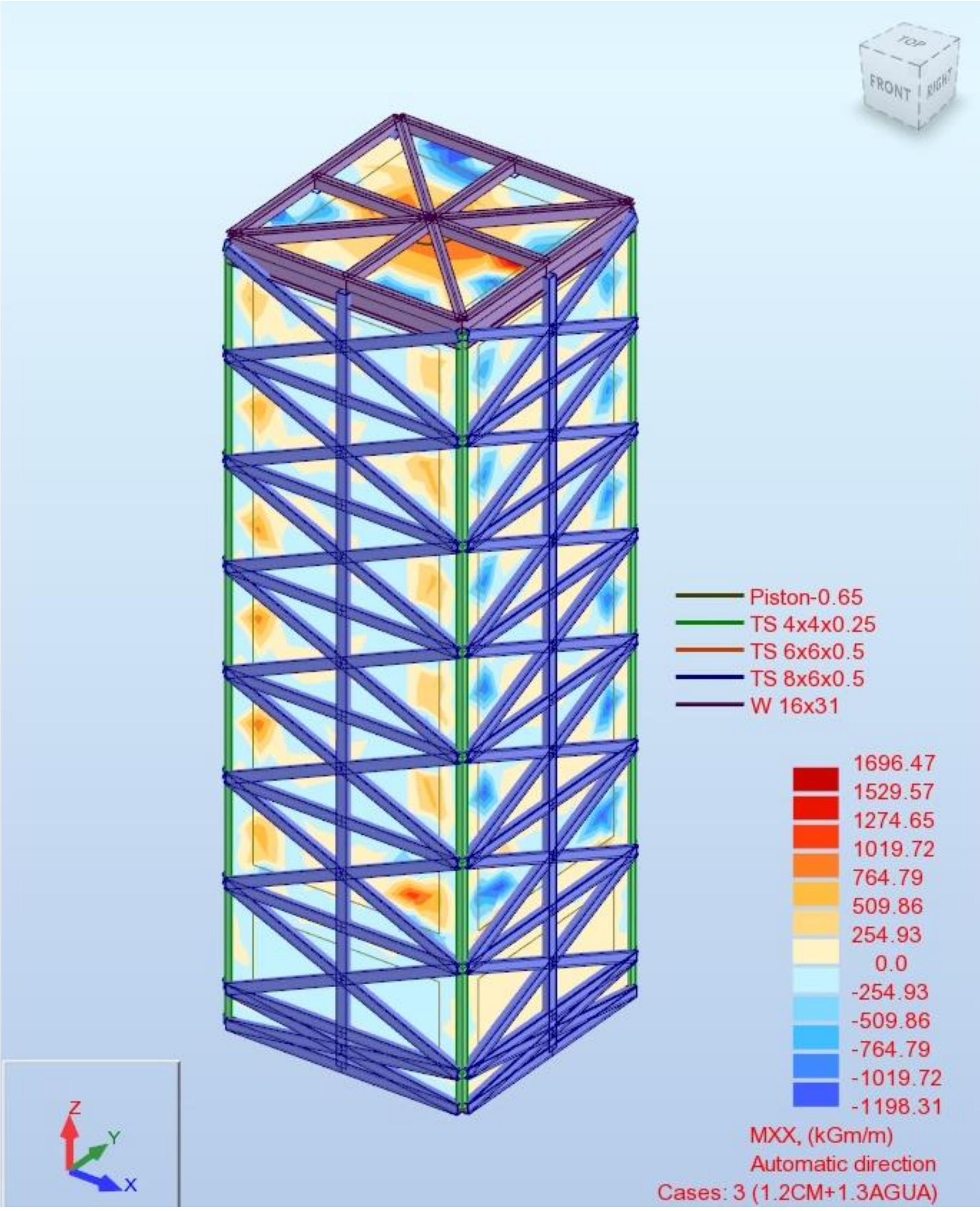

Figure 4: Stresses on Surface of Expanded Device

The square piston's shell is subjected to hydrostatic pressures corresponding to a depth of up to 24.00 meters. Figure 4 depicts the stresses on the square pistons shell. The design was accomplished with the structural design software ROBOT. The stresses are quite high on this shell because air at ambient air pressure fills the inside of the shell through an open standpipe. Figure 5 presents the structural details for the telescoping mechanism, the total amount of steel needed to make this device is 55 tons for the square piston and 40 tons for the square sleeve.

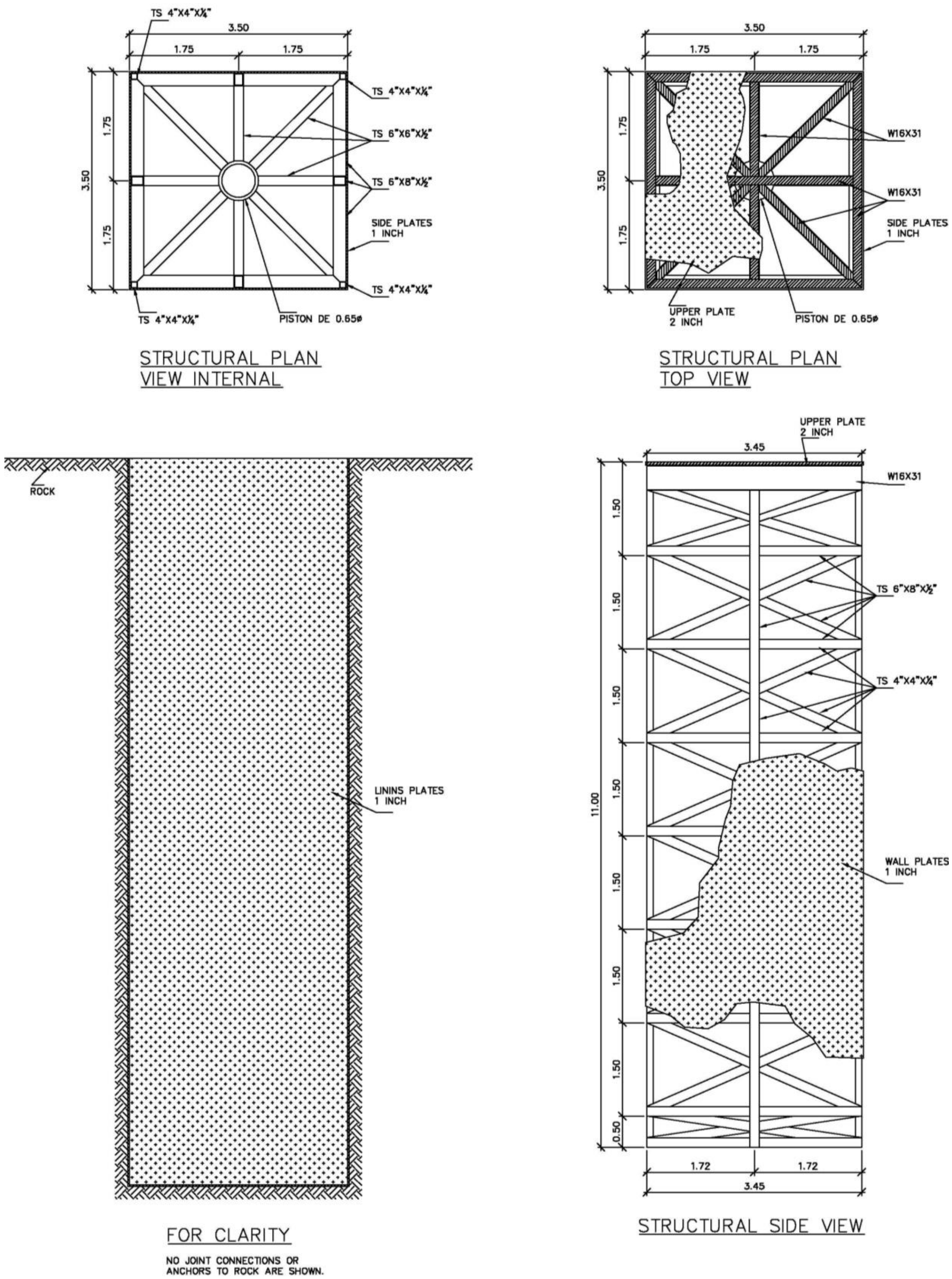

Figure 5: Structural Plans of Device

The hydraulic power circuit includes a pump, a storage cylinder, and an energy accumulator. The hydraulic piston is 60 cm in diameter and has a travel of 8.6 meters, the piston has a capacity of 250 tons. The energy accumulator allows the pumps to run continuously further reducing the power requirement.

The device interior is at ambient pressure. There is a stand pipe open to the atmosphere to the device. The square piston must slide in an out without leaking water from the locks. A sump pump is added to address minor leaks.

6. INSTALLATION OF THE DEVICE

Figure 6 are the installation plans of the device at the Panamax Locks, both the plan view and the cross section are shown. The plans depict the installation scheme to achieve maximum floor coverage without disrupting the locks hydraulic filling system of culverts. The number of units per lock chamber is 384. The floor coverage is 40%. The portion of the floor, where the units are installed, corresponds directly to the water savings achieved through the use of the units. Saving all of the water added to raise the ships in the lock chamber requires the complete coverage of the floor. The water savings can be expressed as water saved without increasing the number of transits or as additional transits if the same amount of water is consumed. The construction time is mostly devoted to the excavation.

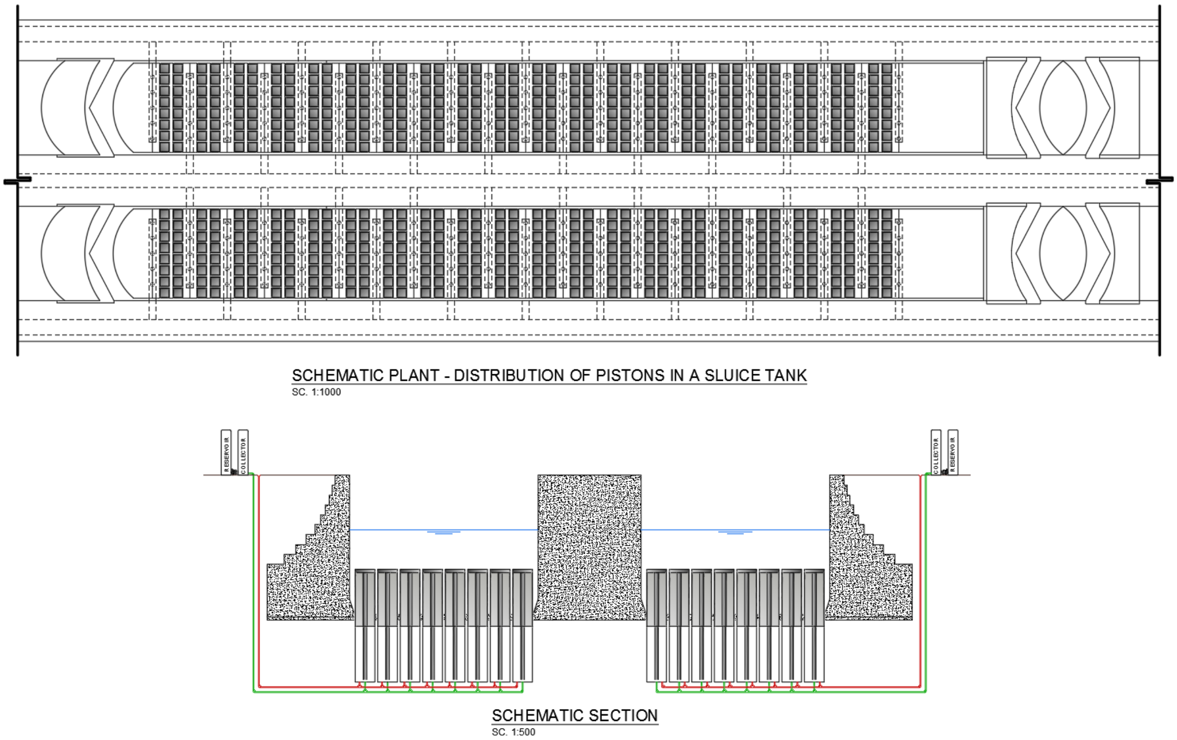

Figure 6: Plan View of Complete Installation at Panamax Locks (40% of floor area results in 40% water savings)

The installation of the device has important considerations. The unit is prefabricated before installation. The lock lane is taken out of operation for the excavation of the hole in which to place the device, the construction of the piping network and the installation of the prefabricated device. The lane outages, for installation, should be limited to less than 15 days.

The foundation material is agglomerate rock for the Pacific Panamax Locks and Gatun rock at the Atlantic Panamax Locks. The excavation starts with the construction of a slurry wall along the perimeter of the excavation. The slurry wall is anchored, where necessary, such that the excavation will not harm the existing lock structure. Figure 8 depicts stresses on the anchored slurry wall and the existing lock structure. The excavation will encompass the installation of one or more units. The calculations of stresses on the slurry wall were calculated with finite element geotechnical software PLAXIS.

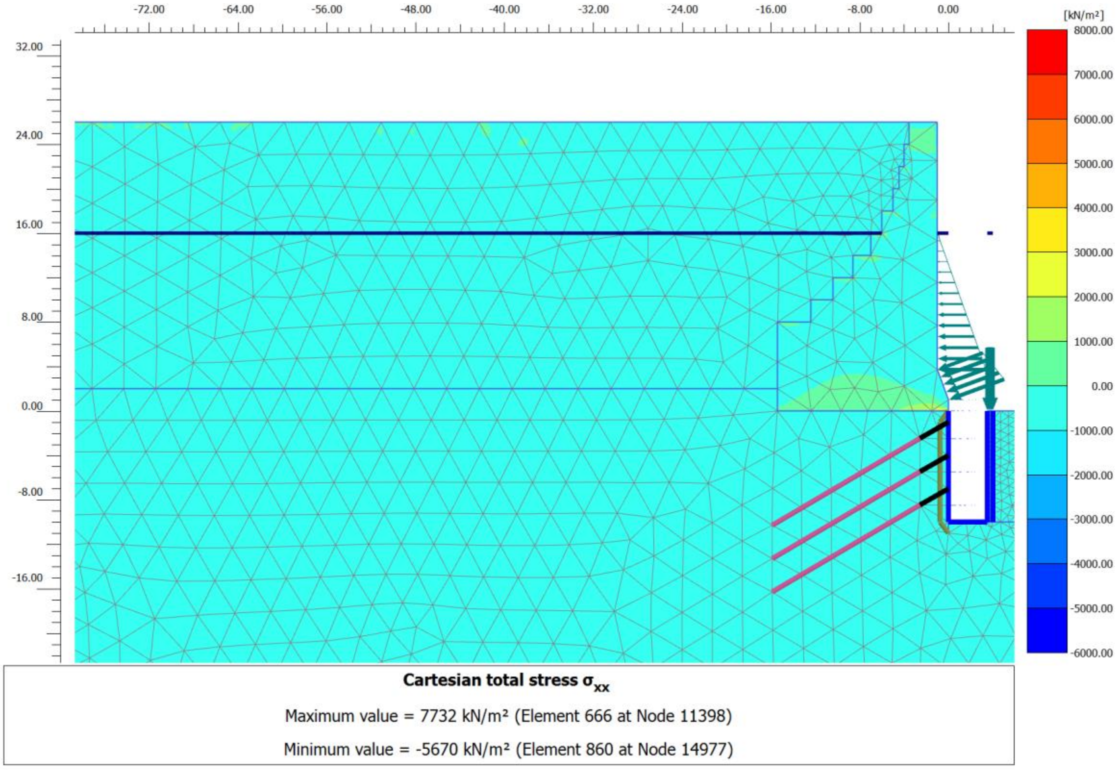

Figure 8: Stresses on Lock Wall and Slurry Wall during Construction

A key issue is system reliability. A malfunctioned unit can simply be taken out of operation in the closed position without any meaningful effects on lock operations. The units can be repaired simply by replacing the piston with a prefabricated unit. However, workers can also enter the device through a hatch to fix effectively minor repairs without removing the unit.

7. BENEFITS AND COST CONSIDERATIONS

The volume of water saved by one-unit is 103 m3. The benefit from the device is cumulative, the benefit is directly proportional to the number of units installed. Full coverage of the chamber floor with these units would allow raising the water level in the chamber without adding water. However, only one unit needs to be installed at each of the six Panamax Locks to achieve savings in water usage.

Table 1 presents the construction costs estimated for the fabrication and installation of the device. The cost of each unit is estimated at $2,000,000. The operating costs are not estimated but they are considered to be lower. The cost of electricity is a small fraction of the sales price. The main component of the operating costs will be equipment maintenance.

	Quantity	Unit Cost	Cost
Fabricated Steel Device	95 Ton	10,000 $/Ton	950,000 $
Hydraulic Power System	1 Unit	500,000 $/unit	500,000 $
Excavation	200 m3	2,000 $/m3	400,000 $
Installation	1 unit	150,000 $/unit	150,000 $
Total Cost			2,000,000 $

Table 1: Installed Cost for a Single Unit

The benefits obtained from this device have already been described in a general way. However, in order to evaluate the viability of installing the device, the economic benefit is estimated. For this simple analysis, the only economic benefit considered is obtained from using the now idle capacity of the Panamax Locks, 15 transits per day. The installation considers the maximum coverage of 40% of the chamber floor, which provides the water savings for these 15 additional transits.

Two investment schemes are considered. The first scenario aims for the minimal investment, namely, the installation of only one unit per lock, 6 total. The second scenario aims for maximum water savings, without compromising the locks existing hydraulic system. This scenario requires the installation of 384 units per lock, 2304 total. The total costs are obtained multiplying the number of units by the unit cost of the installed unit. The benefit is obtained by multiplying the price of an average transit by the number of additional transits possible with the device, or only a fraction (1/384) of a transit possible with the minimal investment strategy. The cost of an average transit for this analysis is considered $300,000 which is less than the maximum toll possible. Table 2 presents the cost and benefits of the two investment schemes. The scope of the investment, between these two extremes would depend on traffic projections.

	Units ()	Cost ($)	Additional (transits/day)	($/transit)	Annual Revenue ($)
Minimum Investment	6	12,000,000	0.04	121,000	1,725,195
Maximum Benefit	2,304	4,608,000,000	15	121,000	662,475,000

Table 2: Revenues and Construction Costs for Two Scenarios

8. CONCLUSIONS

- The ratio of initial costs to annual benefits appears to show that investment in this technology promises favorable returns, regardless of the scope of the investment.
- The installation of this device will make the operation of the Panama Canal more reliable by eliminating the interruptions due to droughts.
- The installation of this device will also increase the reliability of the potable water supply.
- The device can be installed without any delay because there will not be an adverse environmental impact.
- This device can be adapted to the Neo Panamax Locks, where the value of water is greater.
- The device could be incorporated in the construction of smaller locks to incorporate regional commerce.
- The device can be adapted to navigation locks elsewhere, where hydropower is limited, if only seasonably.

The author has patented the device “Air Lift Lock” at the Ministry of Commerce of the Republic of Panama. Also, the process to obtain international patents is currently underway. The intellectual property rights for the device belong to the author.

REFERENCES

Panama Canal Authority (Through FY 2009). Canal Transits / Capacity. Chart published by Panama Canal Authority.

Panama Canal (FY 2017). Panama Canal Annual Report. Reference for Data on Panama Canal.