INNOVATIONS IN LOCK EMPTYING & FILLING SYSTEMS

(Based on InCom WG29 – Version 20b – Final Report)

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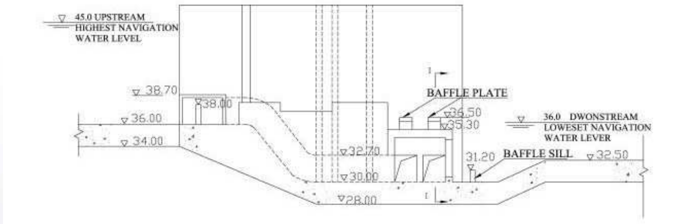
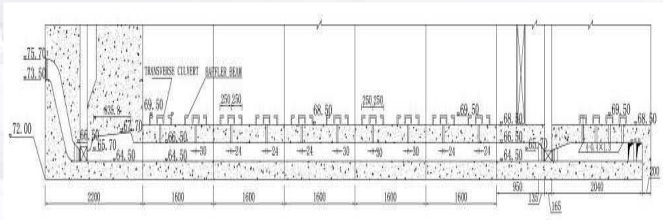
- Layout of Hydraulic Systems
  - Types of Hydraulic Systems
  - New Concepts in Hydraulic Systems
  - Selection Guidelines
  - Water Saving Concepts
- Technical Aspects of Lock Design
  - Developments in Hydraulic Analysis
  - Hydraulic Aspects of Design

LAYOUT OF HYDRAULIC SYSTEMS

- Two Types of Hydraulic Systems
  - "Through the Heads"

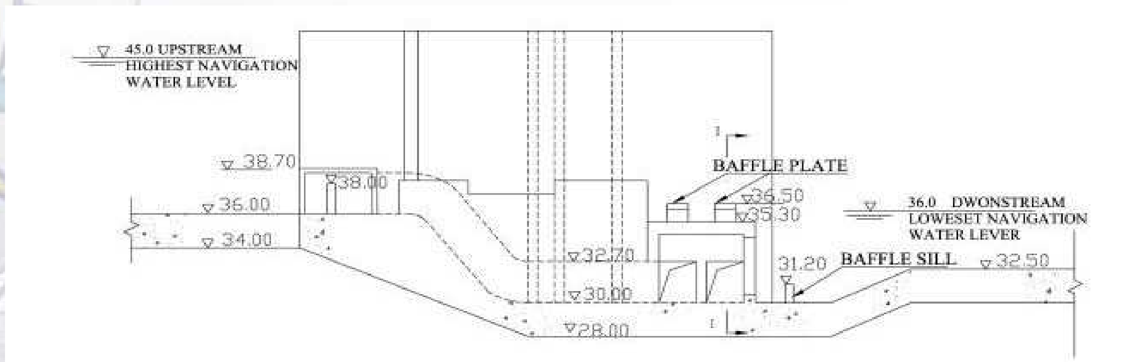


  - "Through Longitudinal Culvert"



TYPES OF HYDRAULICS SYSTEMS

- "Through the Heads" System
  - Short culvert in heads
  - Gates with integrated valves
  - Use lock gates as valves



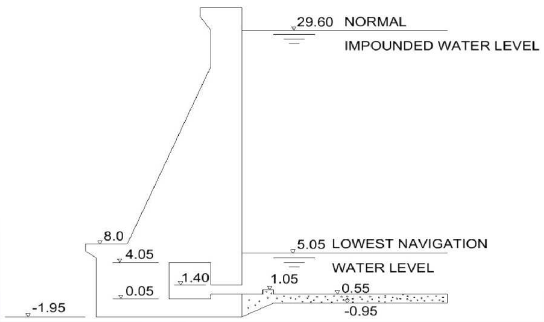
Filling system through the head and with short culvert system with a complex energy dissipation chamber (Fig. 4.12)

TYPES OF HYDRAULIC SYSTEMS

- “Through the Heads” System
  - Use may induce dangerous currents and waves within the lock
  - Solutions:
    - Lock can be operated with a very slow valve schedule
    - Lock can be equipped with an energy dissipation system to reduce the current and waves
    - Lock can be monitored continuously to avoid safety hazards, so that a lock keeper can bypass the automated filling/emptying mode
- Filling/Emptying procedure should be carefully planned and validated before use

TYPES OF HYDRAULIC SYSTEMS

- “Through Longitudinal Culvert” System
  - Asymmetric distribution of flow along the length of the lock chamber
    - Wall culvert side port system
    - In Chamber Longitudinal Culvert System (ILCS)

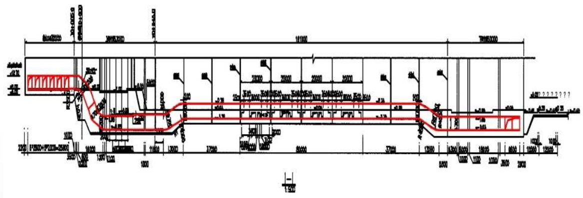


Wall Culvert Side Port System (Fig. 4.13)

In Chamber Longitudinal Culvert System (ILCS) (Fig. 4.16)

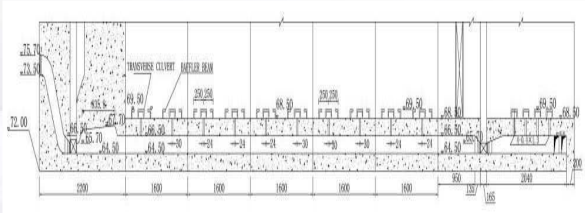
TYPES OF HYDRAULIC SYSTEMS

- "Through Longitudinal Culvert" System
  - Asymmetric distribution of flow
    - Wall culvert bottom lateral system



Wall Culvert Bottom Lateral System (Fig. 4.14)

    - Wall culvert bottom longitudinal system
    - Longitudinal culverts under the lock floor



Longitudinal Culverts Under the Lock Floor (Fig. 4.18)

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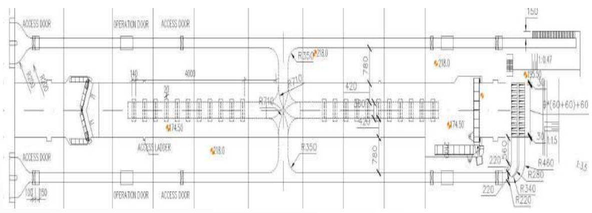
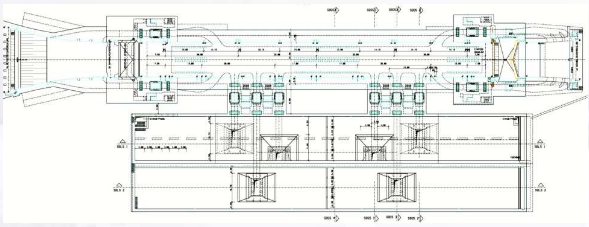
TYPES OF HYDRAULIC SYSTEMS

- "Through Longitudinal Culvert" System
  - Symmetric distribution of flow along the length of lock chamber
    - Dynamically balanced lock filling system



Dynamically Balanced Lock Filling System (Fig. 4.19)

    - Pressure chamber



Pressure Chamber Filling System under Lock Floor (Fig. 4.20)

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TYPES OF HYDRAULIC SYSTEMS

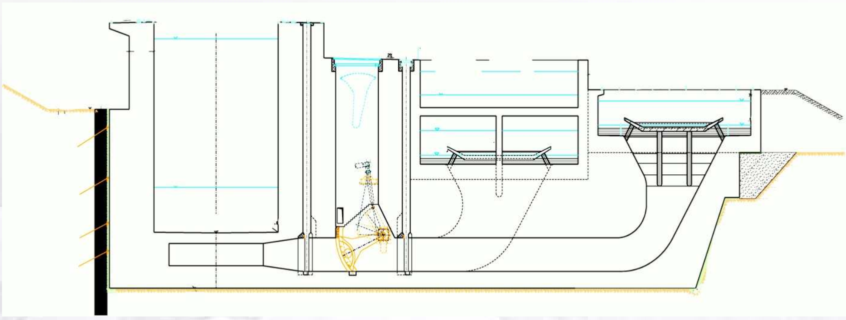
- Longitudinal culvert systems can be divided into three categories, as follows, based on complexity :

Complexity Categories of Longitudinal Culvert Systems (Table 4.9)

Complexity	Hydraulic Systems
1. Simple	- Wall culvert side port system
longitudinal	- In Chamber longitudinal system
culvert systems	system (ILCS)
	- Wall culvert bottom later system
	- Longitudinal culverts under the lock
2. More complex	floor
longitudinal	- Wall culvert bottom longitudinal
culvert systems	system
	- Longitudinal culverts under the lock
	floor
3. Very complex	- Dynamically balanced lock filling
longitudinal	system
culvert systems	- Pressure chamber under the floor

LAYOUT OF HYDRAULIC SYSTEMS

- New Hydraulic System Concepts (Developed after 1986)
  - Pressure chamber system
    - Connected to main chamber through arrays of nozzles
    - Results in a smooth filling of the chamber and a short filling time
    - Has proven very effective, particularly in combination with water saving basins



Connection of Pressure Chamber to Water Saving Basins (Fig. 4.21)

NEW CONCEPTS

- Pressure chamber system (cont'd)
  - When designed, it is important to balance the number and diameter of the nozzles against the size of the chamber and the culverts.
  - If there are too few nozzles, flow into the chamber will be uneven, causing turbulence on the water surface.
  - System should be balanced so the hydraulic loss for the filling process is governed by the nozzles in the floor rather than the hydraulic losses in the inlet, culverts or pressure chamber.

NEW CONCEPTS

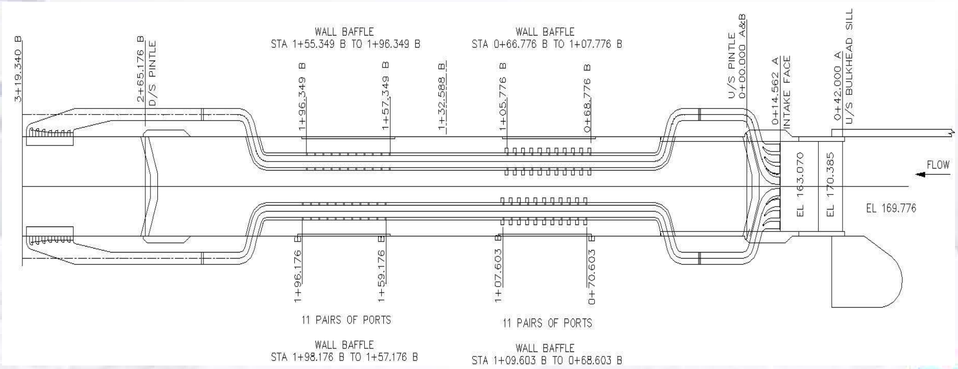
- Pressure chamber system (cont'd)
  - Nozzle size should be estimated using the following ratio of cross-sectional areas:

$$\alpha = \sum_{nozzles} A_{nozzle} / \sum_{culverts} A_{culvert}$$

  - When α is small (<1), the filling process is slower but smoother.
  - When α is larger (>1.5), the filling process is faster but rougher.
  - Rule of thumb: $A_{pressure\ chamber} \geq A_{feeding\ culverts}$
  - Studies have shown that smaller values of α provide the best results (Minden, Germany).

NEW CONCEPTS

- In-chamber Longitudinal Culvert System (ILCS)
  - Design Philosophy: Develop a system that performs almost as efficiently as the side-port filling and emptying system
  - Culverts in the chamber walls are replaced by culverts in the floor of the chamber.



In-Chamber Longitudinal Culvert System (ILCS) – Marmet Lock (Fig. 4.15)

NEW CONCEPTS

- In-chamber Longitudinal Culvert System (cont'd)
  - Allows for alternative lock wall construction, such as RCC or in-the-wet construction
  - Optimized port extensions and wall baffles can provide a uniform distribution of flow into the chamber during filling. They can also assist in energy dissipation.

In-chamber Longitudinal Culvert System (ILCS) – Marmet Lock (Fig. 4.16)

NEW CONCEPTS

- In-chamber Longitudinal Culvert System (cont'd)
  - Can result in significant savings under specific conditions, such as a construction in rock
  - Investigations show that increasing water depth in the chamber allows for a slight improvement in operation speeds.

SELECTION GUIDELINES

- When selecting a filling and emptying system, five factors should be taken into consideration:
  - lift height
  - filling/emptying times
  - lock chamber sizes
  - permissible investments for the lock
  - maximal forces on the vessel
- Generally, the admissible forces on the vessel and the filling time govern.
- Additionally, it is necessary to determine a balance among *lift, safety, cost* and *efficiency.*
  - Lift and safety are determined by the specific project and hawser forces, and cannot be changed. Therefore, cost and efficiency must be balanced.

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SELECTION GUIDELINES

- A good filling/emptying system should follow five principles:
  - Filling time should be as short as possible (based on the specified capacity and construction costs).
  - Water movement and turbulence in the chamber must be limited. The forces on the vessels and thus in the hawsers must not exceed established criteria.
  - Entrapment of large air bubbles in the filling system must be avoided.
  - Cavitation should be avoided if economically possible; otherwise adequate protective measures must be taken.
  - Currents in lock approaches should be reduced to a minimum so that there will be no adverse effect on vessels waiting to lock or maneuvering in the approaches.

SELECTION GUIDELINES

- Two, simple approaches for determining most efficient hydraulic system:
  - Lock lift height
  - M coefficient (Chinese Code, 2001)
    - To be covered in another presentation

- Lift height (H) Approach
  - Design is based on the lift height, following the table below:

• Low lift height	$H < 10m$
• Intermediate lift	$10m < H < 15m$
• High lift	$15m < H$

  - **Note:** This classification was derived for inland waterway navigation and is not valid for seagoing vessels and sea locks.

SELECTION GUIDELINES

- "Low lift locks"
  - A through the heads system or simple longitudinal culvert system may be used (Level 1, Table 4.9).
  - A short culvert system may require an advanced energy dissipation chamber if a short filling time is required.
  - The filling process is not balanced along the chamber length.
- "Intermediate lift locks"
  - A wall culvert side port system and simple longitudinal culvert system may be suitable (Level 1 or 2, Table 4.9).
    - Wall culvert side port system; longitudinal culverts under the floor with side outlets; longitudinal culverts under the floor with top outlets
  - The filling process is better balanced along the chamber length.

SELECTION GUIDELINES

- "High lift locks"
  - Require a more complex/advanced culvert system (level 2 or 3, Table 4.9)
    - "Two sections dynamically balanced" lock filling system; "four sections dynamically balanced" lock filling system; "pressure chamber" system for locks with WSBs
  - It is necessary that the filling process is as symmetric in relation to the chamber as possible.

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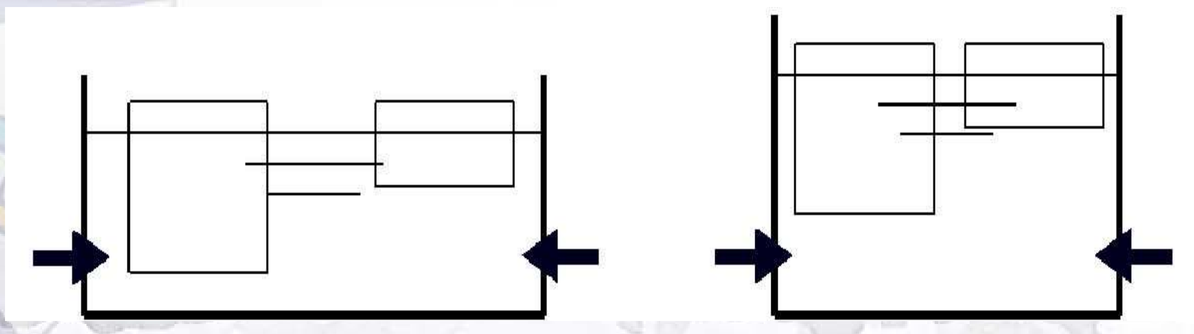
SELECTION GUIDELINES

- Factors unaffected by lock lift height analysis:
  - Overall lock size (length x width)
    - Complex systems could be inappropriate due to cost
  - Lock dimensions
  - Flow variations
    - How fast flow velocity is changing during the locking
    - Tend to lead to waves in the chamber
    - Can induce longitudinal forces against vessel and miter gates, or transverse forces against hull of the vessel
  - Transverse forces, caused by the following processes, can be major problems:
    - Asymmetric filling system/operation
    - Asymmetric position of vessel
    - Jets which directly touch the hull

SELECTION GUIDELINES

- Transverse Force Example: The locks below have the same cross sectional area. However, the flow of water into the lock causes direct transverse forces on a vessel in one configuration, but not on the other.



Impact of the wall culvert side port system (bad configuration on the left, better one on the right) (Fig. 4.23)

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SELECTION GUIDELINES

- Additional Selection Criteria
  - If leveling is not carried out uniformly over the entire length of the lock chamber, longitudinal loads will also act on the vessels.
    - With wall culverts and even longitudinal culverts, discharge is not uniformly distributed along the lock length.
    - Uniform distribution can be enhanced by using bigger culverts and, more significantly, by using symmetric systems.
  - Dimensioning of the culverts is also influenced by the need to limit cavitation and wear in the culverts.
    - Although flow speed is not a sufficient criterion, many countries place limitations on the average flow speed allowed in the culverts.
    - Cavitation is largely influenced by the pressure field and the shape of the hydraulic system.

SELECTION GUIDELINES

- Additional Selection Criteria (cont'd)
  - For locks with a deep and perforated bottom (longitudinal culverts under lock floor, pressure chamber below floor, etc), flow enters the lock vertically through small holes in the floor.
    - If the volume of water beneath the floor is great and there are a great number of holes distributed regularly throughout the surface of the floor, water is transferred uniformly by the bottom of the lock chamber into the lock chamber.
    - Only very small waves are generated even when the rate of flow varies during the locking. Moored ships are not heavily loaded in the longitudinal and transverse directions.

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WATER SAVING CONCEPTS

- Determination of Saving Needs and Selection of the Water Saving System
  - Defined during the studies of water resources management taking into account the following:
    - Assumed traffic
    - Evaporation
    - Infiltration
    - Canal watertightness
    - Climate changes
  - The global water saving system of the lock is a combination or choice of different systems:
    - Pumping
    - Water Saving Basins (WSBs)
    - Intermediate gate inside the chamber
    - Twin synchronized locks (parallel locks)
    - Lock ladder

WATER SAVING CONCEPTS

- To select the best water saving system, the various systems have to be designed and optimized simultaneously by a technical and economic assessment in relation with the existing lift height and the energy cost.
- The main choice criteria for selecting a system or a combination of systems are:
  - Construction cost
  - Operation cost
  - Energy saving and environmental cost
  - Filling time and traffic
  - Available space
  - Influence on water level in the upper and lower reaches

WATER SAVING CONCEPTS

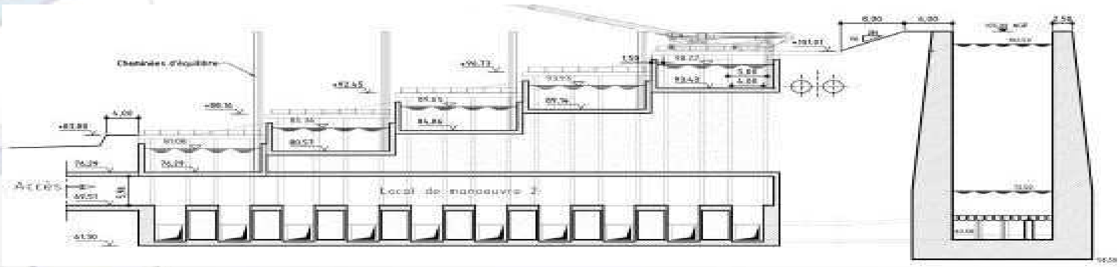
- Examples of Criteria Use:
  - Twin synchronized locks can be accepted only if they are economically justified by the traffic.
  - An intermediate gate may be a good solution only if a significant number of lockages are to be made with small boats.
  - A lock ladder has many advantages over a single lock, but it increases the number of gates and ship operations (mooring, etc.), therefore lowering the traffic capacity.
  - Although water saving basins lead to high initial investment, complex structure, numerous gates, and longer filling/emptying times, they are best when the need for water saving is permanent and larger than a minimum value (case-specific) because of reasons of life cycle cost, energy saving, and environmental cost.

WATER SAVING BASINS

- Historic Use
  - Locks with integrated water saving basins were first built in 1928 in Germany. They are still in operation with no major problems reported.

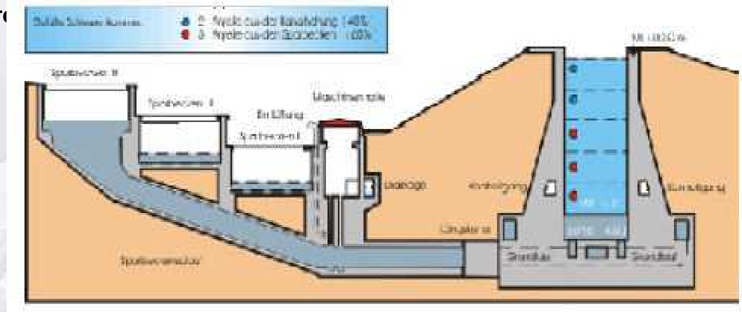
- Recent Examples
  - 3rd lane of the Panama Canal (proposed)
  - Seine Nord Europe Canal (proposed)
  - Uelzen, Germany (2006)
  - Hohenwarthe, Germany (2003)
  - Rothensee, Germany (2001)
  - Rhine-Main-Danube (RMD): 20-30 years of successful use

WATER SAVINGS BASINS



Example of a lock with separated WSBs in France (Seine Nord Europe);

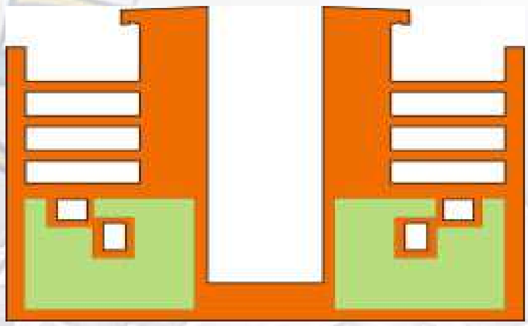
Cross section thr … mber (Fig. 4.27)

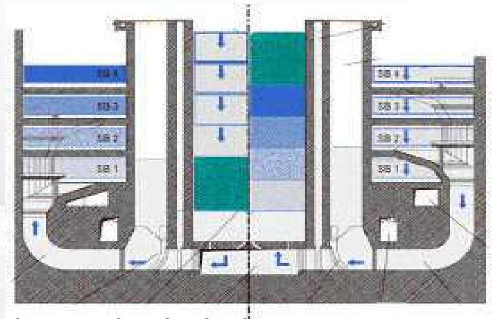


Rothensee Lock (2001 – Mittellandkanal) (Fig. 4.26)

WATER SAVING BASINS

Uelzen I Lock (1976 – Elbe-Seiten Canal) before construction of Uelzen II (Fig. 4.26)





Cross-sections of lock sidewalls with integrated saving basins,
Uelzen II lock with 4 integrated water saving basins and different concrete compositions (Fig. 4.28)

WATER SAVING BASINS

- A lock with water saving basins (WSBs) better fits to filling/emptying systems with longitudinal culverts and inlets on the sidewalls or even distributed through the floor because the successive openings/closures of valves induce significant discharge and therefore higher risk of disturbance of the water level on the lock chamber (balancing waves along the lock chamber).

WATER SAVING BASINS

- Key Points for Optimization of Water Saving Basin Design
  - Optimization of the basin dimensions and parameters:
    - n: Number of saving basins
    - m: $\frac{\text{Area of saving basin}}{\text{Area of chamber}}$
    - e: Pressure head difference when closing valves

    The values of these parameters determine the water saving rate.
  - Hydraulic optimization in order to decrease the filling time
    - The most significant improvements of such a system relate to the design of the global hydraulic system, especially through optimization by numerical and physical models
      - Example: Studying the synchronization of the valve openings and closures
    - Numerical models make it possible to test a large number of configurations
      - Number of WSBs, diameters and positions of culverts, etc.

WATER SAVING BASINS

- Key Points for Optimization of Water Saving Basin Design (cont'd)
  - Division into symmetrical half saving-basins to facilitate the maintenance and reduce the impact in case of a problem (closure of ½ basin versus 1 basin). That may be a useful solution if a short filling time is required.
    - In this case, half basins can be placed symmetrically on both sides of the lock.
  - It is better to have multiple culverts between a basin and the chamber for reliability reasons and to avoid a high degradation of performance during the maintenance of a valve or a culvert. With multiple culverts per basin the water distribution along the axis can be enhanced and thus faster filling can be achieved (for a higher building cost).

WATER SAVING BASINS

- The choice of hydraulic filling system (i.e. through the heads system, simple longitudinal culvert system, etc.) must be done considering the real water lift height between 2 basins. However, when the use of the WSBs is economically relevant, that also means that the lock lift height is rather important and that a reduced filling time is expected.
- Thus an advanced and performing hydraulic system is generally needed.

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HIGH RISE NAVIGATION LOCK USING WSBs

- Traditionally, the maximum lift height of a lock is considered to be limited at 25, 30, or 45m due to the hydraulic aspects, mainly cavitation.
- If WSBs are used, there is no limit for the lock height. Locks of 100 or 150m can be considered if the filling and emptying of each WSB is studied to avoid cavitation.
  - Cavitation limits the height of the saving basins but not their number and therefore the total lift height of a lock.
    - Example: A lock of 100m lift height with 6 water saving basins is similar for cavitation and hydraulic aspects to a series of four locks of 25m lift height.