Water Saving Basins in Navigation Lock Design

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Water Saving Basins

Since water on the inland rivers in the United States is relatively plentiful, the Corps of Engineers has not included water saving basins in the design of navigation locks. Some other locations, however, do not have such a dependable supply and rely on water saving basins to recover some of the water used during lockages. Some canals in Europe, for instance, are used to connect rivers near their sources and cannot draw sufficient water from them for sustained lockages (Figure 1). Other locks are fed by lakes that may have insufficient inflow or capacity to supply sustained lockages; in extreme cases, the water from the lock chamber is pumped back into the upper pool.

Figure 1. Water saving basins on a canal in Germany

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A typical navigation lock loses the entire volume (V_L) of water in the chamber between upper and lower pool to the downstream channel (Figure 2a). Water saving basins provide a means for the recovery, temporary storage and reuse of water during operation of the lock (Figure 2b). They store a portion of the water (S) from the lock chamber during an emptying cycle reducing the volume lost to the lower pool (V_l). This portion is then used to partially refill the lock chamber during the next filling cycle thereby reducing the volume of water taken from the upper pool to finish filling the chamber. Depending on the number of basins used, realistic water savings of 33 to 60% are possible.

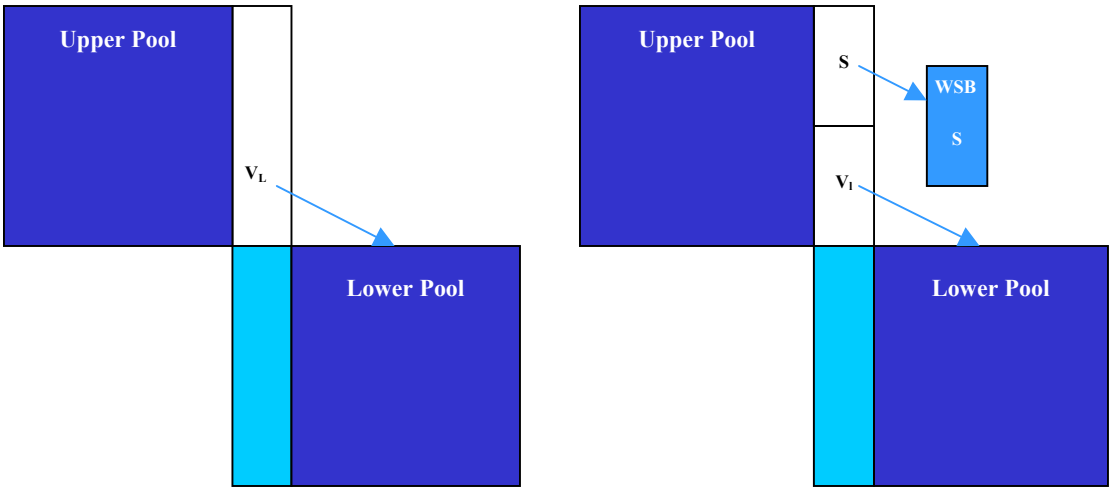

Figure 2. **a.** Typical lock **b.** Lock with water saving basin

Theoretical Water Savings

The Permanent International Association of Navigation Conferences (PIANC 1982) provides water saving basin design parameters and their effect on water savings. Primary factors that determine the potential for water saving include the number of basins (n), the basin to lock surface area ratio (m) and the basin residual filling depth (e).

For a given lockage lift (H), the theoretical water savings (E) can be computed using Equation 1.

$$E = \frac{n \cdot m \cdot (H - 2e)}{H[(1 + m(1 + n)]} \tag{1}$$

Number of Basins

Since each basin has about the same surface area as the lock, the inclusion of water saving basins in a navigation lock project greatly increases the required area. The minimum number of basins required to achieve the desired water saving efficiency should be used.

For an initial assessment of the required number of basins, values of m = 1 and e = 0 can be assumed in Equation 1. This simplifies the computation of water savings as shown by Equation 2.

$$E = \frac{n}{2+n} \tag{2}$$

A summary of potential water savings for varying values of n is presented in Table 1. The practical upper limit on the number of basins is generally accepted as three (PIANC, 1982) since potential water savings drops off rapidly for higher values of n.

Table 1. Number of Basins vs. Water Savings

Number of Basins	Water Savings [%]
1	33
2	50
3	60
4	67
5	71

Basin Residual Filling Depth

Guidelines presented by PIANC recommend a relatively small basin residual (e = 15 cm) to save time during equalization. It is suggested that time savings can be achieved by reducing the period of inefficient transfer of water that occurs near the end of each basin operation when there is a small head differential between the lock and basin. The net effect would be to shorten the equalization time at the expense of water savings.

Studies completed by the Pittsburgh District suggest that a time savings of approximately 15 seconds can be realized for a basin residual of 15 cm. However, the savings appears to occur because of a reduction in the volume of water being transferred and not an improvement in the efficiency of water transfer as suggested by PIANC. A possible explanation is that the inefficient transfer at low heads that might be expected with a falling head type situation does not occur in lock operations due to the inertial head that develops as the flow decelerates. More studies would be required to verify these effects.

The opposite approach to basin design would be to allow for a small negative basin residual during basin operations. Because the residual is relatively small, the overtravel that normally occurs with lock and basin operations could be used to capture additional water in the basins. The net effect of this approach is to lengthen the equalization time while increasing water savings. In either case, the influence of basin residual on equalization time and water savings is relatively small.

A zero basin residual is recommended for initial design of the basins. The lock and basin filling and emptying control system could be designed with the flexibility to

operate with a basin residual as needed. During periods of adequate water supply, a positive basin residual could be used to reduce equalization times. A negative basin residual could be put into effect during critical low water periods to maximize water savings.

Basin to Lock Surface Area Ratio

Increases in water savings can be realized for values of m greater than one, but the benefits are relatively small and inefficient considering the additional space requirements for each basin. For example, increasing the surface area of each basin by 50% results in a net increase in water savings of less than 5%. A more efficient increase in water savings may be achieved by adding an additional basin. Since basin to lock area ratios greater than one provide an inefficient approach to saving water, a ratio close to one (m = 1) is recommended.

For designs that incorporate a basin residual, the basin area ratio can be used as a tool to offset the reduction in water savings. For example, a two basin design with a lift of 6 meters and a residual of 15 cm would require an area ratio of m = 1.25 to maintain a water savings of 50%. The influence of area ratio and filling depth on theoretical water savings is presented in Figure 2.

Studies completed by the Pittsburgh District for this type of design suggest that the time savings are negligible for residuals in the suggested range of 15 cm with an associated area ratio in the range of 1.25. This further supports the previous conclusion that the effects of inefficient water transfer at the end of a basin operation are not significant. Again, more detailed studies are required for verification.

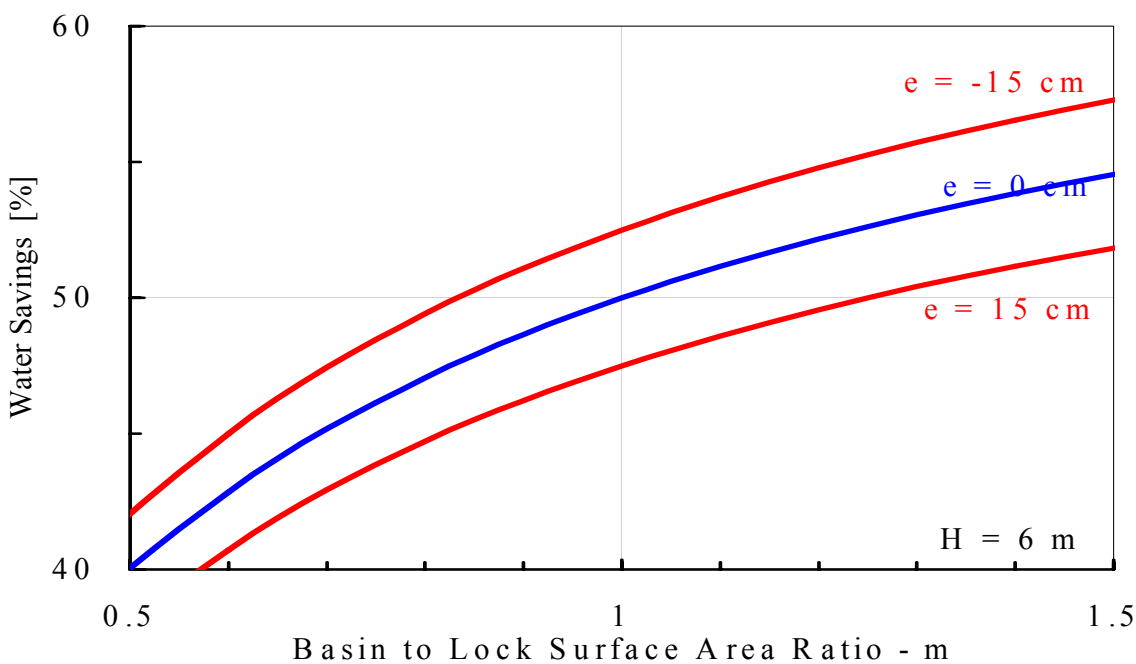

Figure 2. Theoretical Water Savings for Two Basins

Basin Elevations

The theoretical floor elevation and operating water surface elevation for a given water saving basin can be computed using Equations 3 and 4. In the equation, EQ_l is the lower pool equalization elevation of the lock.

$$Floor_i = EQ_l + i\,m\,\frac{(H-2e)}{1+m(1+n)} + e \qquad for\ i = 1\ldots n \tag{3}$$

$$Water\ Surface_i = EQ_1 + (i\,m+1)\,\frac{(H-2e)}{1+m(1+n)} + e \qquad for\ i = 1\ldots n \tag{4}$$

Effect of Variable Lift

Theoretical estimates of water saving percentage computed with Equation 1 assume an idealized condition for a specific lift. Varying levels of the upper and lower pools will result in a range of possible lifts. The analysis of water savings can be complicated somewhat by this condition. Because the floor and operating water surface elevations of a basin are influenced by the lift, there will be a range of possible floor and operating water surfaces from which to select a design. Maximum water saving will be achieved by selecting the minimum floor elevation and maximum operating water surface. The minimum floor elevation is computed from the combination of the minimum upper and lower pool elevations. The maximum operating water surface is computed from the combination of the maximum upper and lower pool elevations. This design approach can result in relatively high and costly water saving basin walls that will overlap with adjacent basins. Increasing the floor elevation and/or decreasing the operating water surface of the basins could realize cost savings with the tradeoff of a reduction in water saving capacity. Selection of design floor and operating water surface elevations requires a comparison of water savings versus cost.

Water Saving Basin Floor Elevations

A duration analysis, considering the entire range of possible upper and lower pool combinations, can be conducted to determine the range of possible basin floor elevations.

The duration analysis will show the range of possible water saving basin floor elevations with resulting ranges of water saving percentages. A selection based on maximizing the water saving percentage would favor a low floor alternative. A selection based on minimizing the initial cost of construction would favor a highest floor alternative.

Operating Water Surface Elevations

Selecting the floor elevations of the water saving basins will allow the equalization elevations of the basins and locks to be determined. The range of possible basin equalization elevations can be determined the same way that the basin floor elevations are evaluated. Results from the duration analysis used to select the basin floor elevation can be used to determine the range of possible basin equalization elevations.

Figure 3 shows an example of varying operating water surface elevations in the locks and water saving basins for a lock with two water saving basins.

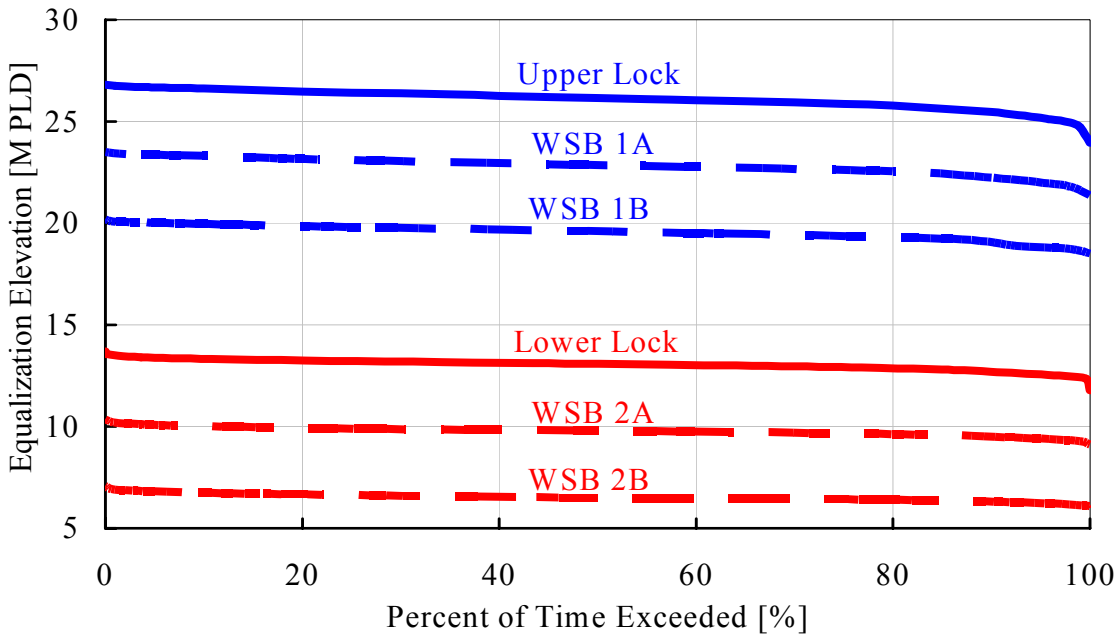

Figure 3. Equalization Elevation Durations for Water Saving Basins and Locks

Numerical Model

Analysis of the various design parameters for the basins under a variable lift condition cannot be readily accomplished using Equations 1, 3 and 4 alone. In general, the lift becomes a function of basin parameters due to changes in the equalization levels while the basin parameters are a function of the lift. A solution requires an iterative process that is best accomplished using a numerical model. An EXCEL spreadsheet can be used to perform the required computations - analysis with or without water saving basins, configure the locks and basins independently, evaluate a variable equalization target elevation, and check computed equalization levels against minimum sill clearances. The spreadsheet results can then be verified by comparison with the theoretical water saving basin equations (Equation 1 - 4) and results obtained using LOCKSIM.

Hydraulic Freeboard Requirements

An appropriate amount of freeboard should be selected for the water saving basins. This freeboard should be applied above the maximum operating elevations so that there should always be sufficient freeboard in the basins. This freeboard would then be used to set the minimum top of basin wall elevations for hydraulic design concerns. Other concerns, mechanical or structural, may set the top of the basin walls to higher elevations.

Lock and Water Saving Basin Profile

The water saving basin wall elevations can be selected based on maximum upper and lower pools and the resultant equalizing elevations in the basins. The minimum freeboard should be used to set the minimum top of wall and miter gate elevations for hydraulic design concerns. This freeboard would be applied above the maximum operating elevation so that there will always be at least the minimum amount of freeboard. This eliminates the need to spill water (that volume of water spilled from the basins to prevent flooding over the walls) during high water periods when the locks and basins will equalize at a high level. The recommended water saving basin floor elevations should be selected based on relatively low upper and lower pools. This will ensure that the basins will save water during times when it is most needed and water availability is low.

Figure 4 shows a possible profile for a two lift lock with the ranges of operating water surface elevations in the locks and water saving basins.

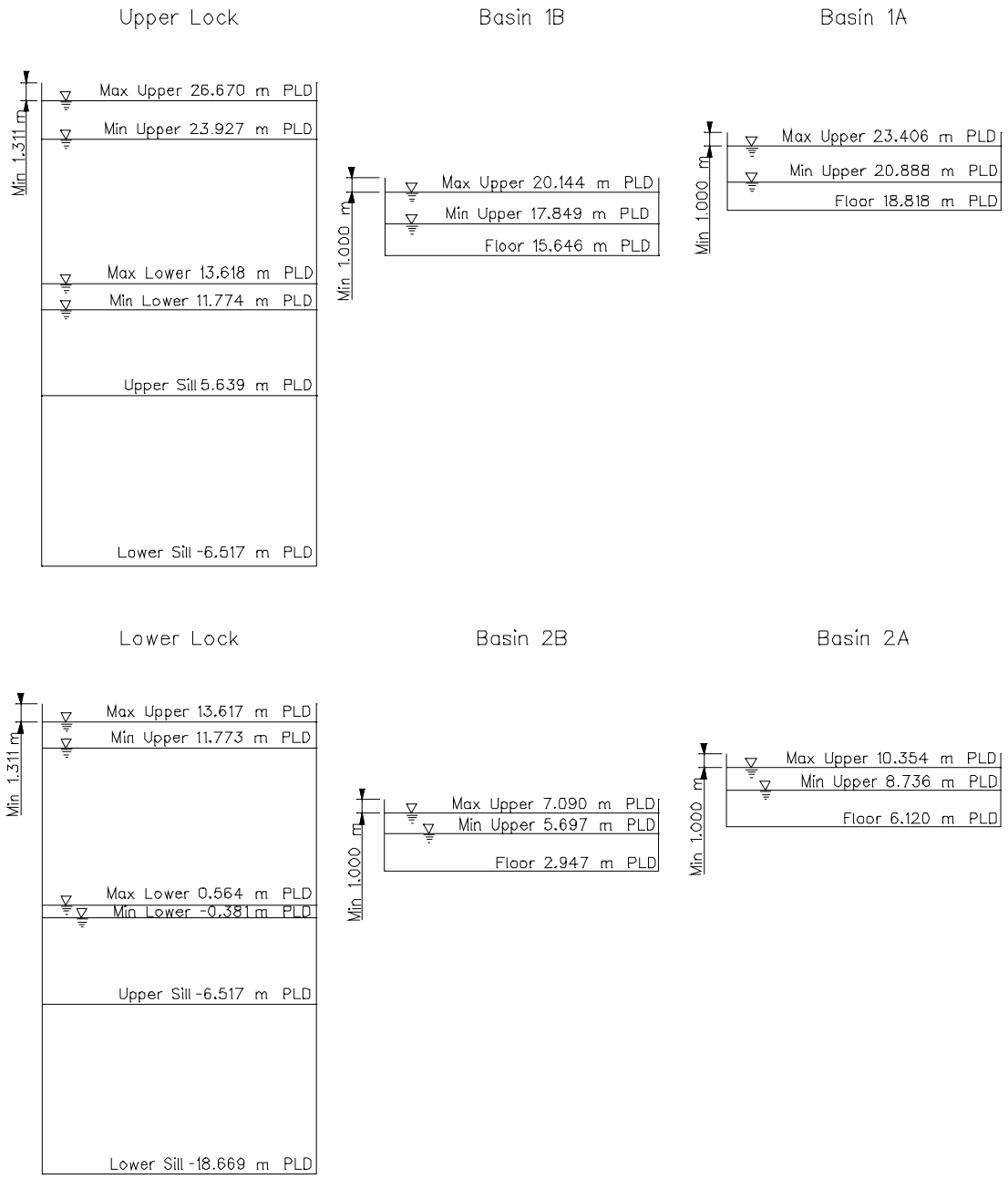

Figure 4. Lock Profile Schematic with Water Saving Basins

Impacts of Water Saving Basins on Lock Operations

The lock and basin filling and emptying systems should have the flexibility to operate with or without a residual in the water saving basins. Operation with a positive residual will reduce equalization times at the expense of water savings. A negative residual will achieve a small increase in water savings. The equalization time reduction due to a basin residual with an equivalent adjustment to the area ratio will be negligible.

To take advantage of this effect, a flexible lock operation plan should be formulated to operate with a basin residual to reduce equalization times during periods of adequate water supply. During critical low water periods, the system could be operated with a zero or negative residual to maximize the amount of water saved. A basin to lock area ratio greater than one is not recommended because it is an inefficient means of saving water and does not have a benefit in terms of equalization time.

Equalization times will tend to be slightly longer with water saving basin use compared to without water saving basin operations because of the reduction in the driving head and the additional valve operations required with use of the basins. Figure 5 shows LOCKSIM generated filling and emptying curves without the use of water saving basins; Figure 6 shows them with the use of water saving basins. The two relative flat areas in the slopes of the filling and emptying curves in Figure 6 show when the rate of discharge decreases as each water saving basin equalizes with the lock chamber.

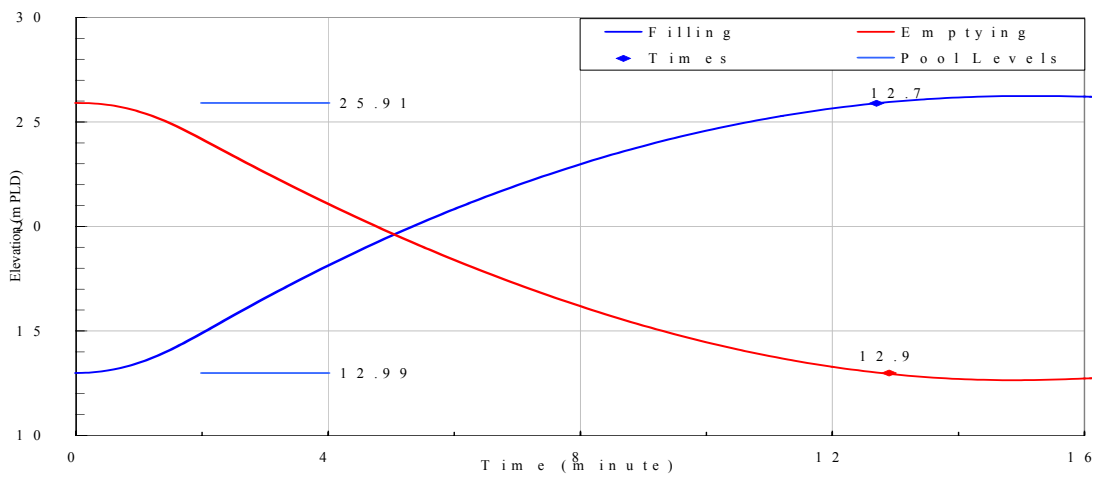

Figure 5. Filling and emptying curves without water saving basins

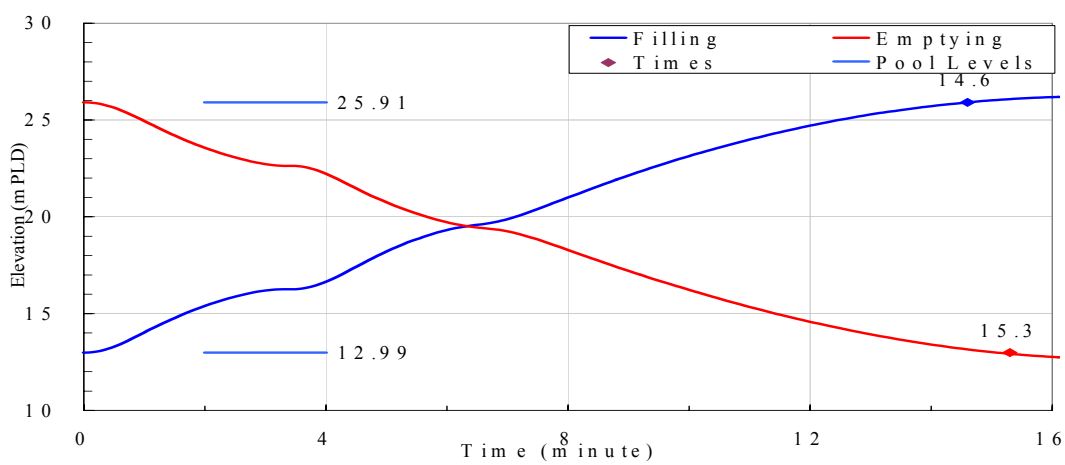

Figure 6. Filling and emptying curves with water saving basins

The end to end water surface slopes in the lock chamber will vary as it is first filled/emptied from/to the water saving basins and then from/to the upper/lower pool. These end to end water surface slopes are important as they determine the forces acting on the hawsers securing a vessel in the lock chamber.

The introduction of the increased flow from the upper pool at about the midpoint in the filling cycle will increase the slopes; similarly the increase of flow to the lower pool will increase the slopes during an emptying cycle. Figure 7 shows LOCKSIM generated filling and emptying curves for a lock chamber without the use of water saving basins; Figure 8 shows the filling and emptying curves with the use of water saving chambers.

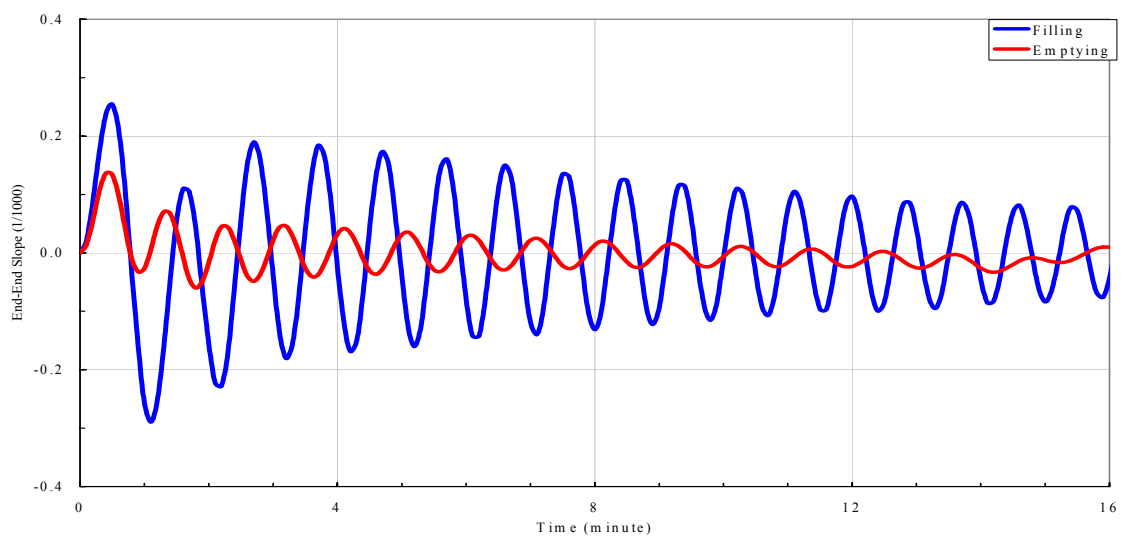

Figure 7. Lock filling and emptying curves without water saving basins

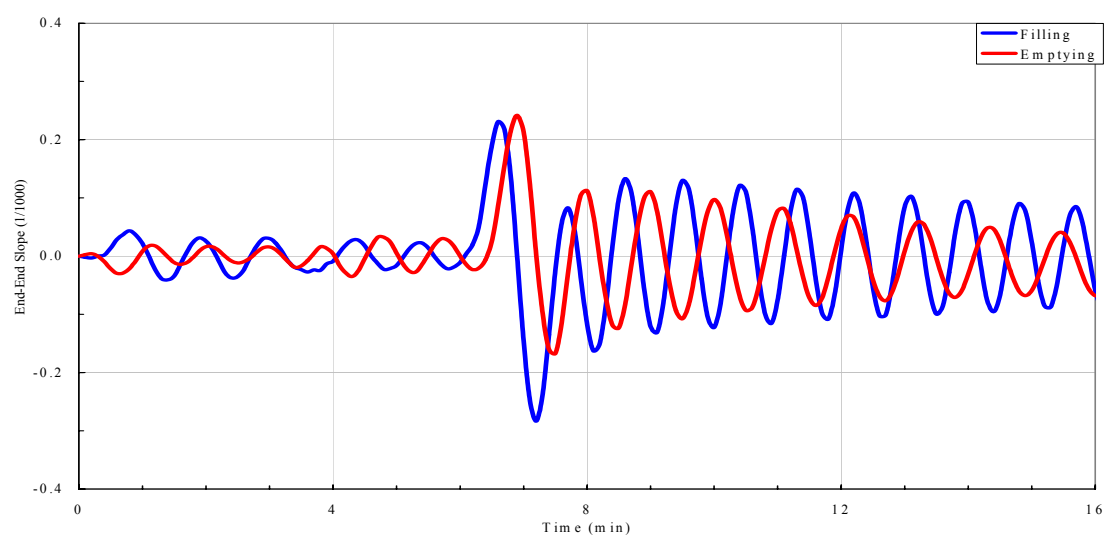

Figure 8. Lock filling and emptying curves with water saving basins

Conclusions

The inclusion of water saving basins in a navigation lock project will save water in the right circumstances. Navigation systems that have limited water sources, such as lakes or canals between rivers, will benefit – realistic savings of 33 - 60% are possible.

However, water savings will come with a cost. The basins will increase the area required for the project, will complicate lock filling and emptying systems and operating plans, and will slow lock filling and emptying times somewhat.

References

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