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A QUARTERLY PUBLICATION FOR WESTERN DAM ENGINEERS

WELCOME!

This is the inaugural issue of the ***Western Dam Engineering Technical Note***. This quarterly newsletter is meant as an educational resource tool for civil engineers who practice primarily in rural areas of western United States. This publication will present technical articles specific to the design, inspection, safety, and construction of small dams. This publication provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

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- Montana Department of Natural Resources
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Article Contributors (URS Corporation):
Jennifer Williams, PE; John France, PE; Jason Boomer, PE; Stan Ellis, PE

Good to Know:

Valuable Low-Cost Reference:
The Embankment Dam Reference Toolbox provides a comprehensive collection of design standards and references for dam engineering available from ASDSO.

Upcoming ASDSO Webinar Dam Safety Training:

- *Tolerable Risk Guidelines for Dams, How Safe is Safe Enough?, by David S. Bowles, Ph.D., P.E., April 9, 2013*
- *Loss of Life Consequence Assessment for Dam Failure Scenarios, by Wayne J. Graham, P.E., May 14, 2013*

ASDSO Training Website

Other Upcoming Training Opportunities:
Best Practices for Inspection, Maintenance, and Repair of Small to Medium Size Dams

In this Issue

Simple Steps to Siphoning

Introduction

This article discusses a practical approach to the design and implementation of siphons – specifically applicable to small-dam owners and operators. Many older dams were not constructed with an outlet or other means of draining the reservoir. Lowering the reservoir may be needed for temporary construction or for emergency response. Siphons can be a low-cost means of providing a reservoir outlet if one does not exist.

Operational Theory

Siphons used in reservoir drawdown operate by atmospheric pressure pushing water over an obstacle (i.e., reservoir water over an embankment dam) and discharging on the other side at a lower elevation than the reservoir. In the same way a barometer works, atmospheric pressure pushes liquid up a siphon into the region of reduced pressure at the top/apex of the siphon. The region of reduced pressure at the top of the siphon is caused by liquid (water) falling on the exit side, creating a pressure differential. The maximum height, or lift, of a siphon is limited by the atmospheric pressure at the site. The height a siphon can lift water will, therefore, be lower for dams at higher elevations (for instance the western United States).

There are several parameters that must be evaluated when establishing the feasibility and design of a siphon. Bernoulli's equation can be applied to estimate a siphon's maximum lift, discharge capacity, diameter, and pressure.

Maximum Siphon Lift

The most critical parameter for a siphon at a given site is to determine whether it is hydraulically possible to 'push' the water the desired height over the dam or spillway crest. The required lift height can be determined by comparing the dam crest elevation (DCE) to the lowest desired reservoir water surface elevation (RWS); see Figure 1. At sea level, atmospheric pressure is generally 14.7 psi which is equivalent to a column of water about 34-ft high. Thus, 34 ft is the maximum theoretical height for a siphon. However, the maximum achievable lift is reduced by friction and other minor losses in the system due to velocity head. Therefore, it is good practice to assume that the maximum lift achievable by atmospheric pressure at sea level is equal to only about 20 to 25 ft of water. Atmospheric pressure can be assumed to decrease by about 4 percent (or 1 ft) for every 1,000-ft increase in elevation. Therefore, the maximum lift height of a siphon can be conservatively taken as:

$$H_{max} = 20' - \frac{RWS}{1{,}000}$$

Where H_{max} = Maximum achievable siphon lift.

RWS = Lowest desired reservoir water surface in feet of elevation

DCE = Dam crest in feet of elevation.

The maximum achievable siphon lift, H_{max}, must be greater than the value of (DCE – RWS). If the dam crest is too high compared to the desired reservoir-drawdown elevation, consider routing the siphon through a spillway or a temporary notch in the dam crest to reduce the required lift.

Predicted Siphon Discharge

Estimating the discharge capacity will help the designer

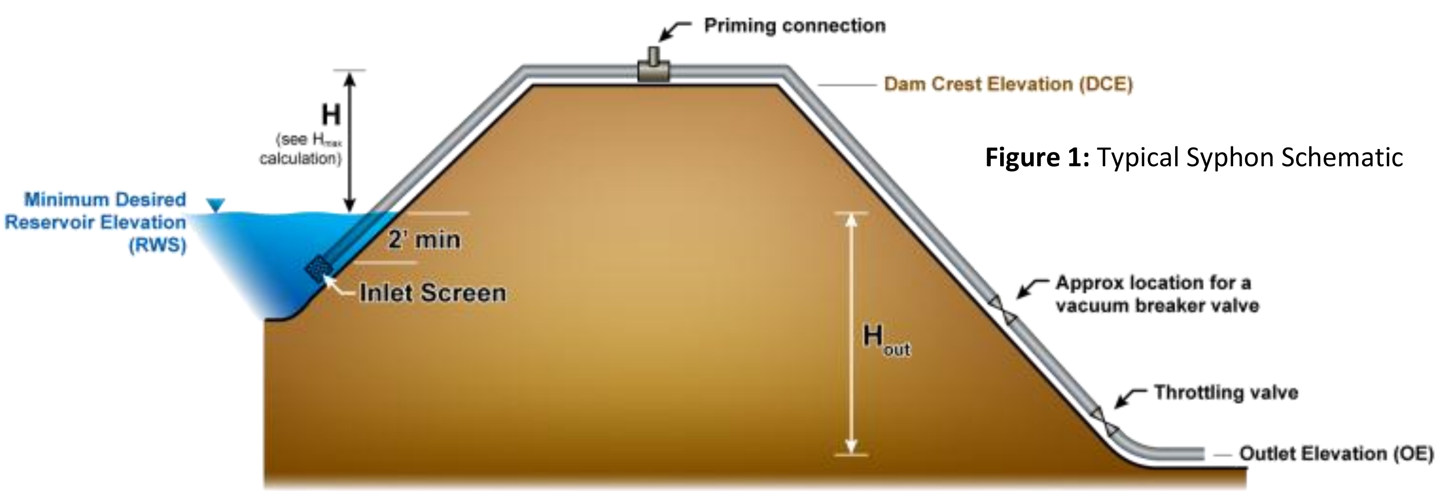

Figure 1: Typical Syphon Schematic

determine the size and number of siphon lines needed. Siphon discharge depends on the difference in elevation between the lowest desired reservoir elevation (RWS) and the elevation of the outlet (OE). Similar to the maximum lift, the discharge capacity is reduced by friction and hydraulic losses. The following variation of the Bernoulli Equation can be used:

$$Q = 0.0438D^{2.5}H_{out}^{\ \ 0.5}(12fL + KD + D)^{-0.5}$$

$$f = 425\left({n^2}/{D^{0.33}}\right)$$

Q = flow in cubic feet per second
D = siphon diameter in inches
H_{out} = elevation difference in feet from the outlet to the lowest desired reservoir water surface (RWS-OE)
K = sum of dimensionless coefficients of hydraulic losses (entrance, bends, valves, exit, etc.). Typical values can be found in most hydraulic reference books
f= dimensionless friction factor
n = Manning's n for the pipe
L = total length of pipe in feet

System Pressure

Vacuum (negative) pressures of the system must be checked carefully to limit the risk of pipe collapse during operation. The lowest pressure often occurs at the apex of the siphon. However, the lowest pressure point can occur downstream of the apex. This occurs when friction and minor losses reduce the pressure in the outlet leg more than the decrease in elevation increases the pressure.

The equation to estimate pressure at the apex can be given as:

$$Y_A = -H - \frac{V^2}{2g}(1 + K' + fL'/D)$$

Y_A = Pressure Head (in feet) at the apex
H = Siphon Lift in feet (DCE – RWS)
K' = sum of minor loss coefficients between the RWS and apex
L' = length of pipe in feet upstream of the apex

CAUTION: The designer needs to evaluate pressures throughout the system to locate the lowest predicted pressure.

If the vacuum pressures are found to be too great for the preferred pipe material, a thicker-walled pipe and/or an air-vacuum breaker valve within the outlet leg will be required.

Design of Siphon Components

Siphon Layout and Valves: In order to help assure that the siphon runs full and that air does not enter and break the siphon through the discharge end of the outlet leg, it is important that the discharge velocity not exceed the inlet velocity. A practical way to help prevent this from happening is to keep the length of the outlet leg (distance from outlet to apex) greater than the length of the intake leg (distance from intake to apex). Another means is having the outlet leg be a smaller diameter than the inlet leg; however, this requires the use of a reducer which increases frictional losses and may reduce the achievable lift height. If needed, a vacuum-breaker valve can be designed and placed along the outlet leg, at an elevation below the lowest drawdown elevation of the reservoir.

It is often beneficial to place an air chamber at the siphon apex, where air will gradually accumulate and could be periodically released. This is particularly good practice for siphons expected to operate for long periods of time.

Intake: The intake needs to be submerged to avoid air entering the system and breaking the siphon. It should be placed a minimum of two feet below the lowest desired reservoir surface elevation to limit air entering through vortex action. Air entering will severely decrease efficiency and could break the siphon. A baffle (such as a piece of plywood or metal) can also be used over the mouth of the intake to limit the vortex.

Outlet: The discharge end of the siphon must be at a lower elevation than the lowest desired elevation of the reservoir. Ideally, it should be submerged to reduce the risk of air entrainment. Air entrainment could break the vacuum and immediately stop the flow. In many cases, submerging the outlet end is not practical. If the outlet discharges to the atmosphere, care should be taken to ensure the outlet pipe runs full, and valves be installed to release air at the apex as further described below. Additionally, if the discharge end is not submerged, precautions should be taken to ensure adequate erosion protection is provided or the discharge end is kept as far from the toe of the embankment as possible.

Pipe size and materials: The hose or pipe comprising the siphon can be constructed of a variety of materials (steel, PVC and HDPE are common), but must be free of kinks or obstructions and must have water-tight joints. Also the pipe should be designed with a wall thickness sufficient to prevent collapse due to negative pressures. Thin-walled plastic pipe and aluminum irrigation pipes are not recommended, because they are typically not strong enough to accommodate negative pressures in siphons.

Although there are no theoretical upper limits to the diameter of a siphon, economics and practicality usually dictate hose/pipe diameters in the range of ¾-inch to 30-inches, but commonly in the range of 2 to 8 inches. Additional siphoning capacity, if needed, is usually provided by more siphon pipes rather than by larger diameter pipes. Also, rather than having a single siphon and valves for conveying and controlling all of the water, it is often best to have several smaller-diameter siphons, with or without throttling valves – so that each can operate independently of the others.

Priming: The siphon must be primed (filled with water) or pumped in order to start the flow of water. Both ends of the siphon tube need to be closed to prime the siphon. A gate or butterfly valve can be used to close the ends of the pipe. This can then be used to control the flow during and after priming. There are two common methods for priming the siphon:

- Fill both the outlet leg and inlet leg of the siphon pipe with water through a fitting at the apex. The fitting must be large enough to allow air to escape as water fills the pipe (i.e. greater than the pump diameter). Place an airtight cap on the fitting when the pipe is full of water and open the discharge valve to begin the flow of water.
- Fill the longer outlet leg with water through a port at the apex. A vacuum pump can be used to draw air out and water in through the inlet side of the siphon. The apex port is then plugged and the discharge valve at the outlet opened to begin the flow of water.

Sometimes an intake valve is used to assist with priming, and, if needed, this valve needs to be opened before the discharge valve to start the flow of water.

Other Siphon Applications

Although this article focuses on the use of siphons for reservoir drawdown, siphons can also be used for dewatering applications during construction, as a means to pass additional inflows under major storm events, or a permanent means for withdrawing water on an on-demand need for reservoirs and canals. The theory and design considerations are the same as described above.

Conclusion

Siphons can, in the correct circumstances, provide a low(er)-cost alternative to drawdown a reservoir. The key operational parameters are: (1) the required hydraulic lift cannot exceed the effective local atmospheric pressure adjusted for vapor pressure and frictional losses; (2) the discharge point of the siphon must be lower in elevation than the body of water to be siphoned; and (3) the pipe or hose used for the siphon must be designed to withstand negative pressures.

Common Pitfalls in Siphoning:

- Ensure required lift height is feasible for site location and elevation [(H_{max}>(DCE-RWS)]
- Check pipe strength against collapse. Lowest pressure does not always occur at apex.
- Ensure outlet velocity does not exceed inlet leg velocity (use a longer outlet pipe length and/or smaller diameter pipe)
- Review need for vacuum break valves, throttling valves, and air chambers as described.

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