Inverted Siphons

Portions of the following were adapted from the USBR publication "Design of Small Canal Structures" (1978)

I. Introduction

- Siphons, or inverted siphons, are used to convey water across a natural depression, under a road, or under a canal
- Siphons are usually made of circular concrete pipe or PVC, connecting two canal reaches in series
- Some siphons have rectangular cross-sections
- Siphons may have a straight lateral alignment, or may have changes in direction

When going across a depression, the siphon should be completely buried, usually with a minimum of about 1 m of cover
- Siphons are like culverts, but instead of sloping down from inlet to outlet, they slope down, then back up to the outlet
- Also, siphons usually have only one pipe (not two or three in parallel, as with many culverts)
- Some siphons have multiple pipes in parallel; for example, when the original flow capacity is to be increased
- In general, siphons are longer than culverts
• Open-channel flumes are alternatives to siphons, but may be more expensive to build and/or to maintain, and may not be aesthetically acceptable
• Siphons can be very dangerous (the time to travel from inlet to outlet is usually longer than a someone can hold their breath)
• Siphons can be very problematic with sediment-laden water because sediment may tend to deposit at the low point(s)
• With large siphons, periodic cleaning is possible, but may be impractical with smaller siphons
• Also, cleaning usually means a significant interruption in water delivery service
• Sometimes gravel and rock can enter the siphon
• However, trash racks and/or screens should always be provided at the inlet

II. Structural Components of Siphons

1. Pipe

• Most siphons are built out of pre-cast concrete pipe (PCP), reinforced with steel in larger diameters
• Concrete pipe head class can go up to 200 ft (86 psi) or more
• Pre-stressed concrete cylinder pipe has steel wire wrapped around the pipe with a mortar coating
• Pre-stressed concrete pipe is typically used on large siphons (over 10 ft in diameter), with lengths of 20 ft, and placed in trench with a special vehicle
• Pre-stressed concrete pipe was previously considered the most economical option for large siphons, but experience has shown that the wire may corrode in only 15-18 years of service (e.g. Salt River project in Arizona)
• Older siphons have been built out of asbestos-concrete (AC) mixtures, but this has been discontinued in the USA due to health risks from exposure to asbestos
• Siphons can also be built with plastic or steel pipe, including other less common possibilities (even wood)
• USBR siphon designs always have a single pipe, or barrel, but this is not a design restriction in general, and you can find siphons with two or more pipes in parallel
• USBR siphon designs always have circular pipe cross-sections

• A siphon in the Narmada canal in India was recently built to carry 40,000 cfs (1,100 m³/s) across a depression; it has multiple rectangular conduits in parallel
• The Central Arizona Project (CAP) has four large siphons with 21-ft diameter prestressed concrete pipe; some of these have already been replaced because of corrosion and subsequent structural failure

2. Transitions

• Transitions for siphons are the inlet and outlet structures
• Most siphons have inlet and outlet structures to reduce head loss, prevent erosion and piping, and maintain submergence ("hydraulic seal")
• It can be very hazardous to omit inlet and outlet structures because these locations are often at steep embankments that would erode very quickly in the event of a breach or overflow
• An emergency spillway is sometimes located just upstream of a siphon inlet
• Transitions in smaller siphons may be of the same design at the inlet and outlet, and standard designs can be used to reduce costs
• With larger siphons, it may be desirable to do a “site-specific” transition design, possibly with different designs for the inlet and outlet

3. Gates and Checks

• Gates and checks can be installed:
  (a) at the entrance of a siphon to control the upstream water level
  (b) at the outlet of a siphon to control upstream submergence

• Operation of a gate at the entrance of a siphon may ensure hydraulic seal, but will not ensure full pipe flow in the downhill section(s) of pipe at discharges below the design value
• It is not common to install a gate at the outlet of a siphon (this is never done in USBR designs)

4. Collars

• Collars may be used, as with culverts, to prevent “piping” and damage due to burrowing animals
• However, with siphons they are not always necessary because the inlet and outlet structures should be designed and built to direct all water into the entrance and exit all water to the downstream channel
5. **Blowoff and Vent Structures**

- A “blow-off” structure is a valved outlet on top of the pipe at a low point in the siphon.
- Smaller siphons often do not have a blow-off structure.
- These structures are used to help drain the siphon in an emergency, for routine maintenance, or for winter shut-down.
- Blow-off structures may have man holes (or “person access holes”) on large siphons to allow convenient entry for manual inspection.
- Blow-off structures can be used to periodically remove sediment from the pipe.
- Continuous-acting vents are installed in some siphons to remove air during operation (this is usually an after thought when “blow-back” (surging) problems are manifested).
- Others have simple vertical pipes to vent air from the pipe, but these can have the opposite effect.
- Air can become trapped, especially in long siphons, during filling; filling of the siphon should be gradual, not sudden.
- Some blow-off structures are of the “clamshell” type, with top and bottom leaves off of a tee at the bottom of the siphon.
- Clamshell blow-offs are not so common, but have definite advantages in terms of avoiding cavitation (handling high velocity flows at large heads) compared to butterfly valves, for example.

6. **Canal Wasteways**

- A wasteway (side-spill weir) is sometimes built in the canal just upstream of a siphon inlet to divert the canal flow in the case of clogging of the siphon or other emergency situation.
- Also, the inlet to a siphon should always have trash racks and/or screens to prevent rocks and other debris from entering the pipe.
- If the inlet is at a canal turnout, the design should have a forebay to calm the turbulence before entering the siphon; otherwise, air entrainment may be significant.

7. **Safety Features**

- In operation, siphons can appear to be harmless, especially in a large canal, but can be deadly.
- Just upstream of the siphon entrance the following may be used:
  - posted signs with warnings
  - ladder rungs on the canal banks
  - steps on the canal banks
  - cable with floats across the water surface
  - safety net with cables and chains
  - gratings or trash racks
### III. Design of Siphons

- The design of siphons has many similarities to the design of culverts; however, unlike the design of culverts:
  1. siphons are usually designed for full pipe flow
  2. siphons are usually designed to minimize head loss
  3. siphons take the water down, then back up

- USBR siphon designs are generally for an assumed 50-year *useful life*

#### 1. Pipe Velocity Limit

- According to the USBR, pipe velocities at design discharge should be between 3.5 and 10 fps
- Recent USBR designs have mostly called for 8 fps velocity
- Many small culverts are designed for 10 fps
- In general, lower pipe velocities are fine for small siphons, but in large capacity and or long siphons it is justifiable to design for higher velocities
- Long siphons can cost much less with even a slightly smaller pipe size

#### 2. Head Losses

- Culverts are usually designed for full pipe flow from inlet to outlet (the outlet is almost always submerged, and it is highly unlikely that open channel flow would prevail throughout the siphon – the change in elevation is usually too great)
- Total head loss is the sum of: inlet, outlet, pipe, and minor head losses
- Convergence losses at the entrance are usually negligible, but divergence losses at the exit (outlet) can be significant
- Most of the loss in a siphon is from pipe friction
- Outlet losses are typically about twice the inlet losses
- Minor losses in pipe bends are usually insignificant
- Most siphons are designed to carry the full design discharge without causing an “M1” profile (backwater) in the upstream channel – to achieve this, it is important to carefully estimate head losses
- If the total siphon head loss at the design discharge exceeds available head (difference in upstream and downstream canal elevations and water depths) the siphon will operate at a lower discharge and cause the upstream water level to increase
- A hydraulic jump in the descending part of the siphon (upstream side) will greatly increase the head loss, and may cause problems of surging and “blow-back”
- Blow-back occurs when air is entrained into the water due to a hydraulic jump in the pipeline, or due to movement of a hydraulic jump within the pipe; water and air periodically surge backwards through the inlet
No swimming!

Spillway

Trash racks

Hydraulic jump?

Closure gate enough to have US hydraulic seal for $Q < Q_{\text{max}}$.

"Blowoff valve"

Open every two weeks until water runs clear.

Closure gate enough to push hydraulic jump US and out of siphon.
• Blow-back is usually more problematic in siphons with relatively flat descending (upstream) slopes -- a small change in the downstream head can cause a hydraulic jump to move within the pipe at the upstream end

3. Hydraulic Seal

• The “hydraulic seal” is the minimum required upstream head, relative to the upper edge of the siphon pipe at the siphon inlet, to prevent the entrainment of air at that location
• The hydraulic seal recommended by the USBR is equal to 1.5Δhv, where Δhv is the difference in velocity heads in the upstream open channel and in the pipe (when flowing full)
• For a more conservative value of the hydraulic seal, use 1.5h_{pipe}, where h_{pipe} is the velocity head in the siphon pipe when flowing full

4. Design Steps

• Determine the route that the siphon will follow
• Determine the required pipe diameter according to the design discharge and allowable velocity
• Determine the appropriate transition structure types at the inlet and outlet, or design custom transitions for the particular installation
• Design the siphon layout according to the existing terrain, and the proposed (or existing) canal elevations at the inlet and outlet
• Determine the pressure requirements of the pipe according to the head (at the lowest point) during operation
• Determine the total head loss in the siphon at the design discharge
• If the head loss is too high, choose a larger pipe or different pipe material; or, consider adjusting the canal elevations at the inlet and outlet
• Use Fig. 2-7 on page 30 of Design of Small Canal Structures (USBR) to determine whether blow-back might be a problem, and make adjustments if necessary
IV. Siphon Pressure Rating

- What is the maximum pressure in the inverted siphon pipe? This must be calculated at the design stage so that a suitable pipe is selected.
- The maximum pressure is equal to the maximum of:
  1. Water surface elevation at the outlet minus the elevation of the lowest point in the siphon (unless there is a closed valve at the outlet); or
  2. Water surface elevation at the inlet minus the elevation of the lowest point in the siphon, minus the friction loss from the entrance to the low point.

- In any case, the maximum pressure will be at, or very near, the location of minimum elevation in an inverted siphon
- If a gate or valve is at the siphon exit, and it is completely closed, the maximum pressure will be according to #2, without subtracting friction loss (i.e. full pipe, zero flow condition); otherwise, the zero flow condition pertains to #1
- Note that the above assumes that an open channel is upstream of the siphon entrance, and an open channel is at the siphon exit
- Note that in order to calculate friction loss, you need to assume a pipe diameter (ID) and a pipe material
- Due to possible water surging in the pipe, the pressure may be somewhat higher than that calculated above, so consider adding a 10% safety factor

References & Bibliography