I. General Characteristics of Flumes

- Flumes are often used:
  1. Along contours of steep slopes where minimal excavation is desired
  2. On flat terrain where it is desired to minimize pumping, except perhaps at the source
  3. On flat terrain where it is desired to avoid pumping, except maybe at the water source
  4. Where cross-drainage is required over a depression

- A pipeline or siphon can be considered to be an alternative to a flume in many cases, or to a canal – these days the choice is essentially one of economics
- Aesthetics may make an inverted siphon preferable to a flume for the crossing of a depression, even though the flume could be less costly
- Unlike most canals, flumes seldom have gates or other flow control structures; that is, they are generally used strictly for conveyance

- The average flow velocity in a flume is higher than that for most canals
- But the flow regime in flumes is usually subcritical, as opposed to chutes, which usually operate under supercritical flow conditions
- Flume cross-section shapes are typically rectangular, but may also be semi-circular or parabolic
- Several irrigation systems in Morocco have networks of elevated semi-circular flumes
- Flumes with non-rectangular sections are usually pre-cast concrete, or concrete mixed with other materials
- Flumes may have under-drains, side inlet structures, and over-pass structures to handle cross flows, especially for cross flows going down a slope
Some flumes are elevated for crossing natural channels, depressions, roads, railroads, etc.

II. Flume Design

The hydraulic design of flumes involves calculations of maximum steady-state capacity:

1. Determine the design discharge
2. Select an appropriate route with consideration to total length, construction costs, longitudinal bed slope, need for cross-drainage, and other factors
3. Select a cross-sectional shape (usually rectangular, sometimes circular)
4. Select a material for the flume channel (this will determine the roughness)
5. Use the Chezy or Manning equations to determine the size of the cross section (unless you expect nonuniform flow conditions)
6. Make adjustments as necessary to accommodate the design discharge and other technical, aesthetic, safety, and economic factors

As noted in a previous lecture, the hydraulic efficiency of the cross section may be a consideration, semi-circular sections being the most efficient
Inlet and outlet water levels may be a consideration in the flume design
For example, the flume may be connected to a reservoir with a specified range of water surface elevation
As in any open-channel, avoid flume designs that would produce near-critical flow conditions at the design capacity; attempt to arrive at a design with $F_r < 0.9$
Consider USBR and or other guidelines for the inclusion of freeboard at the design discharge
Note that an overflow could quickly cause severe erosion under the flume

III. Flume Cross-Sections

A variety of cross section shapes have been used for flumes
The most hydraulically efficient section is that which has a maximum value of the hydraulic radius for a given discharge, roughness and side slope
The most hydraulically efficient rectangular section is that with a bed width to depth ratio, $b/h$, of 2.0
According to the USBR, the most cost-effective rectangular sections have a range of ratios from $1 \leq b/h \leq 3$
Cross section of a pre-cast concrete flume used in several irrigation systems in the Dominican Republic
IV. Function of Channel Transitions

- Channel transitions occur at locations of cross-sectional change, usually over a short distance
- Transitions are also used at entrances and exits of pipes such as culverts and inverted siphons
- Below are some of the principal reasons for using transitions:
  1. Provide a smooth change in channel cross section
  2. Provide a smooth (possibly linear) change in water surface elevation
  3. Gradually accelerate flow at pipe inlets, and gradually decelerate flow at pipe outlets
  4. Avoid unnecessary head loss through the change in cross section
  5. Prevent occurrence of cross-waves, standing waves, and surface turbulence in general
  6. Protect the upstream and downstream channels by reducing soil erosion
  7. To cause head loss for erosion protection downstream; in this case, it is an energy dissipation & transition structure

V. General Comments about Transitions

- Transitions at pipe, flume, and canal outlets (ends) often have energy dissipation structures included or added to the design
- Transitions are typically made of concrete or earth, the latter often having some sort of riprap protection
- Earthen transitions between open-channel and pipe flow (culverts and siphons) are often acceptable when the velocity in the pipe is less than about 3.5 fps (1 m/s)
- Transitions can have both lateral and vertical (bed) contraction or expansion
- The optimum angle of lateral convergence (at contractions) is given as 12.5° by Chow (1959), corresponding to a 4.5:1 ratio
- The optimum angle of lateral divergence (at expansions) is often taken as approximately 9.5°, or a 6:1 ratio
• This divergence ratio is used in a number of expansion transitions in open channels, pipes, nozzles and other devices

• It is very difficult to design transitions that work well over a wide range of flows
• Consequently, transitions are often designed for specified maximum flow rates

• The theoretical analysis of hydraulics in transitions is limited, especially when the analysis is for one-dimensional flow
• Three-dimensional analysis is usually required to predict the occurrence of waves and to estimate head loss under different conditions, but even this is often inadequate
• Physical models are required, in general, for reliable evaluation of the performance of a particular transition design under various flow conditions
• Some day, mathematical models will be up to the task

VI. Standard USBR Transitions

• Standard designs are selected for many small transitions because the time and effort to design a special transition for a particular case may not be justified, and because the engineer may not know how to go about designing a transition based on the application of hydraulic equations
• The most common type of transition used in small canal structures by the USBR is called “broken back” (Type I), which has vertical walls on the converging/diverging sides

• For small structures (about 100 cfs or less), the USBR usually applies one of five standard transition designs
• Standard USBR transitions are given in Chapter VII of the “Design of Small Canal Structures” (1978) book and other publications and design reports
• More sophisticated transitions may be designed for larger flow rates

• Many of the USBR transitions are inlet and outlet structures for pipes, not transitions between channel cross section changes
• Many open-channel-to-pipe transition designs call for a transition length (in the direction of flow) of about three times the diameter of the pipe
• The length can also be defined by a specified angle of convergence or divergence, knowing the upstream and downstream channel widths

• For earthen transitions the minimum length may be given as about 5 ft or 2 m

• Inlet transitions to inverted siphons are generally designed such that the top of the pipe is below the upstream open-channel water surface for the design discharge (this is to help prevent the continuous entry of air into the siphon, which reduces capacity)

• The USBR calls the difference in elevation between water surface and top of pipe opening the “hydraulic seal”

• Inlet transitions for culverts are generally designed such that inlet control occurs, possibly causing supercritical flow and a downstream hydraulic jump inside the pipe (barrel)

VII. Computational Design Procedures

• A change in cross-sectional size or shape will generally cause a change in water surface elevation

• However, in some cases it is desirable to avoid surface elevation changes and backwater profiles

• This can be done by calculating one or more dimensions of the cross sections such that the water surface elevation continues on a uniform downhill gradient through the transition for a specified “design” discharge

• This is possible for subcritical flow only, not for supercritical flow

• The head loss in inlet transitions is typically taken to be about $0.1\Delta h_v$, where $\Delta h_v$ is the change in velocity head from upstream to downstream across the transition

• For outlet transitions, the loss is usually about double this, or $0.2\Delta h_v$

• In some cases, these losses may be twice these values, or more, but $\Delta h_v$ is usually very small anyway, compared to the specific energy

• Another approach, sometimes used in changes of width for rectangular sections, is the reverse parabola transition, consisting of two parabolas which define the bed elevation through the transition, or the channel width through the transition

- parabola 1
- parabola 2

• The second parabola is the same as the first, but inverted vertically & horizontally
• The transition length is determined before the parabola is defined, and the total length of the transition is divided into two halves with the parabola in the second half being the inverted parabola of the first half
• This procedure is described in some hydraulics books
• You can also use a unique 3rd degree polynomial instead of two parabolas by fixing the end points and specifying zero slope at each end
• In many cases the transition can be designed to give a very smooth water surface
• The reverse parabola approach can also be applied to trapezoidal to rectangular cross-section transitions, but the calculations are more involved
• A typical design approach is to use a continuous and uniform reduction in side slope along the length of the transition, with a calculated bed elevation such that the water surface continues as smoothly as possible from upstream normal depth to downstream normal depth