VII. TRANSITION DESIGN

7.1 Basic Considerations

Transitions may be defined as a change in either direction, slope or cross section of the channel that produces a change in the state of flow (Henderson, 1966). Transition design is a critical step in design of open-channel flow networks since the design capacity of the system can be significantly lowered if the transitions do not perform properly. Some of the possible problems that can develop with poorly designed transitions include backwater effects, local scour and wave formation.

There are several conditions where tansitions will be required on surface mine sites. Diversion channels will seldom be identical in shape with the natural waterway above and below. Economic considerations usually dictate designing a smaller, more hydraulically efficient diversion channel than the natural waterway. This is particularly true when riprap is being used to stabilize the channel. Transition sections are also required at changes in grade, such as the inlet and outlet to a spoil fill diversion. These transitions typically represent a change from a mild to a steep slope and from a steep to a mild slope, respectively. The recommended design for the inlet and outlet of a steep slope diversion on a spoil fill was given in Section 5.4. However, other changes in grade, such as the transition from a mild slope to a milder slope, require consideration. In this case a potential backwater condition exists that could cause overtopping of the upstream channel. Conversely, if a mild slope transitions to slightly steeper slope, the potential for local scour exists.

Transitions must be properly designed to avoid the potential adverse effects discussed above. Transitions are sometimes designed to conserve head, however, this consideration is not particularly relevant to diversion channel design on surface mine operations. Additionally, transitions from one geometric shape to another, such as trapezoidal to rectangular, are relevant in canal design, but not diversion channel design on surface mine sites. Riprap-lined channels on surface mine sites are typically geometrically similar trapezoidal shapes. Therefore, consideration of the more complicated curved or warped transition section is not included in this manual.

The final section of this chapter presents general guidelines related to channel junctions, such as a diversion channel discharging into a natural stream. This condition can be considered as a special type of transition.

7.2 General Design Principles

Transition design is based on the Bernoulli and continuity equations (Equations 4.9 and 4.10); however, experience plays an important part. The Soil Conservation Service (1977) has provided some general rules to follow in designing transitions. They are:

1. The water surface should be smoothly transitioned to meet end conditions.
2. The water surface edges should not at any section converge at an angle greater than 28° with the center line, nor diverge at an angle greater than 25°.
3. In well designed transitions, losses in addition to friction should not exceed 0.10 h_v for convergence and 0.20 h_v for divergence, where h_v is the velocity head.
4. In general it is desirable to have bottom grades and side slopes meet end conditions tangentially.

Transition design is based on a modified form of Bernoulli's equation, (Section 4.3) derived by grouping the various head terms from Sections 1 and 2, or

$$\left(\frac{P_1}{\gamma} + Z_1\right) - \left(\frac{P_2}{\gamma} + Z_2\right) = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + h_L \qquad (7.1)$$

For sufficiently flat slopes $(P/\gamma) + Z$ equals the water-surface elevation, and taking the fall of the water surface in the downstream direction as positive, Equation 7.1 equals

$$\Delta W.S. = \Delta h_v + h_L \qquad (7.2)$$

where $\Delta W.S.$ is the change in the water-surface elevation, Δh_v is the change in the velocity heads and h_L is the head loss term. In a transition section, additional head loss is usually involved over the friction head loss. The additional losses, referred to as conversion losses, can be defined simply as those due to a change in direction of the stream lines resulting in both converging and diverging transitions. In relatively short transitions, the conversion losses are usually significantly greater than the friction losses and so the friction losses can be neglected. The head loss term h_L is then defined as (Chow, 1959)

$$\text{inlets:} \quad h_L = C_i \, \Delta h_v \qquad (7.3a)$$

outlets: $h_c = C_o \Delta h_v$ (7.3b)

where C_i and C_o are the inlet and outlet loss coefficients, respectively. For inlet (converging) structures, the entrance velocity is less than the exit velocity and it is necessary to design the transition with a drop in the water-surface sufficient to provide the required increase in velocity head and to overcome head losses. For outlet (diverging) structures the velocity is reduced and the water surface theoretically rises an amount equal to the reduction in velocity head. The actual rise, referred to as the recovery head, is less than theoretical due to head losses. These relationships can be stated mathematically by incorporating Equation 7.3 into Equation 7.2,

inlets: $\Delta W.S. = \Delta h_v + C_i \Delta h_v$ (7.4a)

outlets: $\Delta W.S. = \Delta h_v - C_o \Delta h_v$ (7.4b)

These simple relationships, plus the continuity equation, form the basis for all transition design. The objective in designing a transition is then to achieve the water-surface change specified by Equations 7.4.

7.3 Simplified Design Procedure

Given two channel cross sections, it is required to design the transition. A simplified transition design procedure where conservation of head is not critical is given by the Soil Conservation Service (1977). The elevation of the water-surface and the flow velocity at the end points are known from the design discharge and channel geometries. However, in the design procedure no attempt is made to trace out the water surface at intermediate points in the transition. The design objective is only to insure that the proper overall change in water surface elevation exists.

In the absence of more specific knowledge the length of the transition should be such that a straight line joining the flow line at the two ends of the transition will make an angle of about 12 1/2 degrees with the axis of the structure. The recommended values of the coefficients C_i and C_i are taken as 0.15 and 0.25, respectively, therefore Equation 7.4 becomes

inlets: $\Delta W.S. = 1.15\ \Delta h_v$ (7.5a)

outlet: $\Delta W.S. = 0.75\ \Delta h_v$ (7.5b)

With the known velocities the change in water surface can then be computed.

For an inlet, the drop in bed elevation through the transition necessary to achieve the required ΔW.S. is

$$\Delta B.E. = d_2 - d_1 + \Delta W.S. \tag{7.6a}$$

where d_1 and d_2 are the flow depths at the entrance and outlet of the transition, respectively. For an outlet the required rise in elevation through the transition is

$$\Delta B.E. = d_1 - d_2 + \Delta W.S. \tag{7.6b}$$

Therefore, following the general rules given in Section 7.2 and the computed length and elevation change, the transition design is complete.

7.4 Transition Protection

The transition design procedure presented in the previous section is a simplified method. Therefore, to ensure that transition stability is maintained, it is recommended that riprap protection be provided in transition reaches. Using the values for flow velocity (V) and depth of flow (d), values of the Froude number can be determined (Section 4.2.5).

If the transition is accomplished on a mild slope where the Froude number does not exceed 0.8, transition protection can be determined from the mild slope riprap design procedure in Section 6.7. To account for the turbulence in the transition section, the value for velocity V used in the parameter $V^2/R^{0.33}$ should be increased by the following amounts:

V = 1.05 times channel velocity for converging channels (accelerating flow)

V = 1.10 times channel velocity for diverging channels (decelerating flow)

Protection should also be provided both up and downstream of the transition reach. Recommended distances are at least three feet upstream of the entrance and at least five feet downstream of transition exit.

For steep sloping transitions where Froude numbers exceed 0.8, transition protection should be evaluated from the steep slope riprap design procedure given in Section 5.3. Transition slopes less than five percent (the minimum slope value in the steep slope design curves) can be designed using the ten percent curves consequently providing conservative rock protection. Protection should be provided at the transition entrance and exit according to the criteria in Section 5.4.

7.5 Special Considerations

The simplified method discussed in Section 7.3 is probably adequate for most transition designs required for diversion channels in a surface mine situation. The method gives a satisfactory design for relatively low velocity, small transition sections. Under higher velocity flows involving supercritical flow and hydraulic jump situations, more detailed design procedures are required. Shock wave formation and other complicating factors must be considered. References for these design procedures include Hinds (1928) and Henderson (1966).

7.6 Channel Junctions

Where a confluence between a major diversion channel and a natural stream channel occurs, the junction should be oriented to provide a good transition of the diversion channel flow into the natural stream flow. If the diversion channel is brought in perpendicular to the stream channel, significant turbulence and waves may be generated at the junction point. This in turn can result in scour and problems of channel instability. Orientation of the diversion channel exit more in the direction of the natural stream flow helps reduce velocity and momentum components (which cause waves normal to the direction of the combined flow) (Soil Conservation Service, 1977).

The natural angle of juncture between tributary streams and main streams has been observed to be in a range of 45 to 55 degrees. At a junction between a diversion channel and a natural stream channel, the diversion channel is essentially a tributary. Therefore, orientation of major diversion channel junctions at angles no larger than 45 to 55 degrees should provide for reasonable transition and assimilation of diverted flows into stream channels. Figure 7.1 shows the recommended orientation.

A major diversion channel, such as one carrying the flow of a diverted tributary stream, should be constructed so that the diversion enters at the invert level of the natural channel. Smaller diversions may be brought in at some point on the channel bank above the stream bed level. When this is the case, adequate protection of the channel banks must be provided by placement

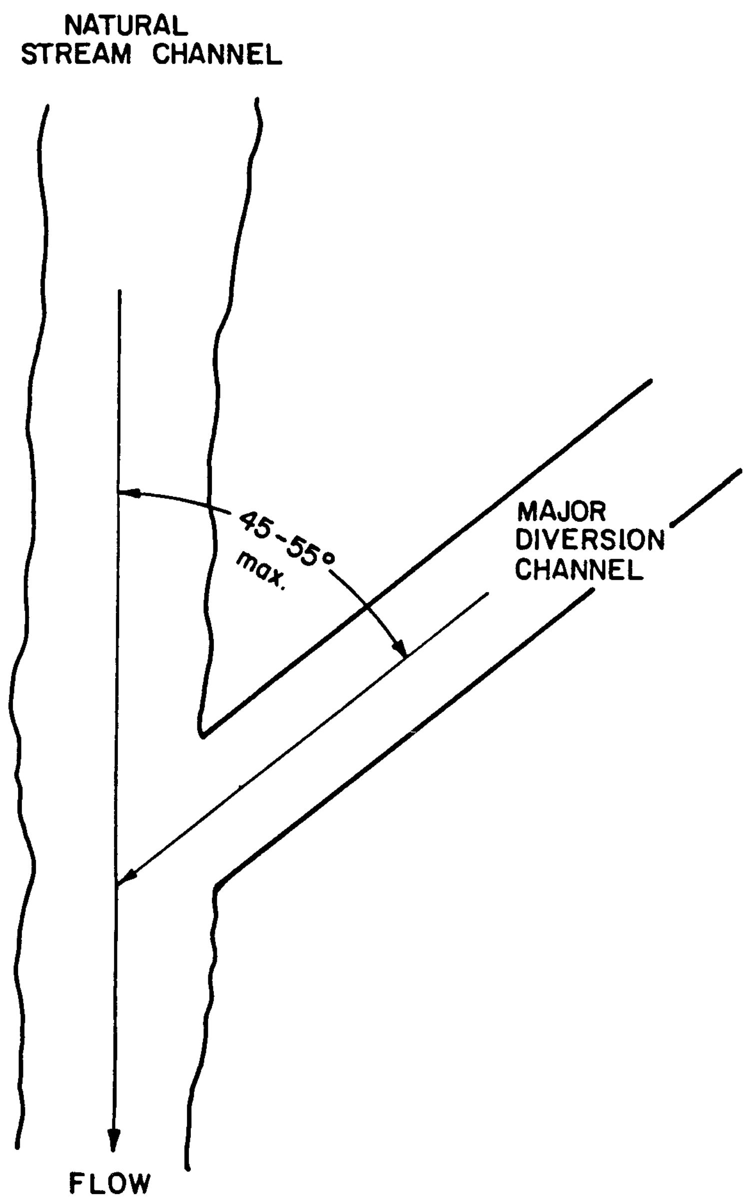

Figure 7.1. Recommended junction angle between a major diversion and a natural stream channel.

of localized riprap. Overland flows entering a diversion channel should be concentrated and brought in at selected locations. Where it is not practical to concentrate overland flows, the channel bank should be protected or vegetated.

7.7 Example of Transition Design

The following example illustrates the transition design procedure. It is required to design a transition between two trapezoidal channels with different cross sections. The characteristics of each channel are:

Upstream Channel Section	Downstream Channel Section
natural smooth earth channel	Riprap lined
$n = 0.025$	$D_{50} = 0.5$ ft
$S = 0.003$	$S = 0.01$
Base width $b = 10$ ft	Base width $b = 6$ ft

flow rate $Q = 150$ cfs

Solution

1) Evaluate upstream channel section properties from data for upstream channel: compute Qn

$$Qn = 150\ (0.025) = 3.75$$

From the charts in Appendix C

$$Vn = 0.112 \qquad V = \frac{Vn}{n} = 4.5 \text{ fps}$$

$$d = 2.3 \text{ ft}$$

2) Evaluate flow properties in downstream channel section

Estimate $n = 0.0395\ D_{50}^{1/6}$ (Equation 4.18)

$$n = 0.0395\ (0.5)^{1/6} = 0.035$$

$$Qn = 150\ (0.035) = 5.25$$

From the charts in Appendix C

$$Vn = 0.20;\ V = \frac{Vn}{n} = 5.7 \text{ fps}$$

$d = 2.5$ ft

3) Compute change in water surface profile (Equation 7.5a)

$$\Delta B.E. = 1.15 \left(\frac{5.7^2}{2g} - \frac{4.5^2}{2g}\right) = 0.22 \text{ ft}$$

4) Compute necessary change in elevation (ΔZ) between transition entrance and exit (Equation 7.6a)

$$\Delta B.E. = d_1 - d_2 + \Delta W.S.$$

$$\Delta B.E. = 2.5 - 2.3 + 0.22 = 0.42 \text{ ft}$$

5) Compute length of transition using maximum angle of convergence equal to 25° between the water surface.

$$\tan (12.5) = \frac{(9.6-8.0)}{L}$$

$$L = 7.2 \text{ ft}$$

Figure 7.2 illustrates the design.

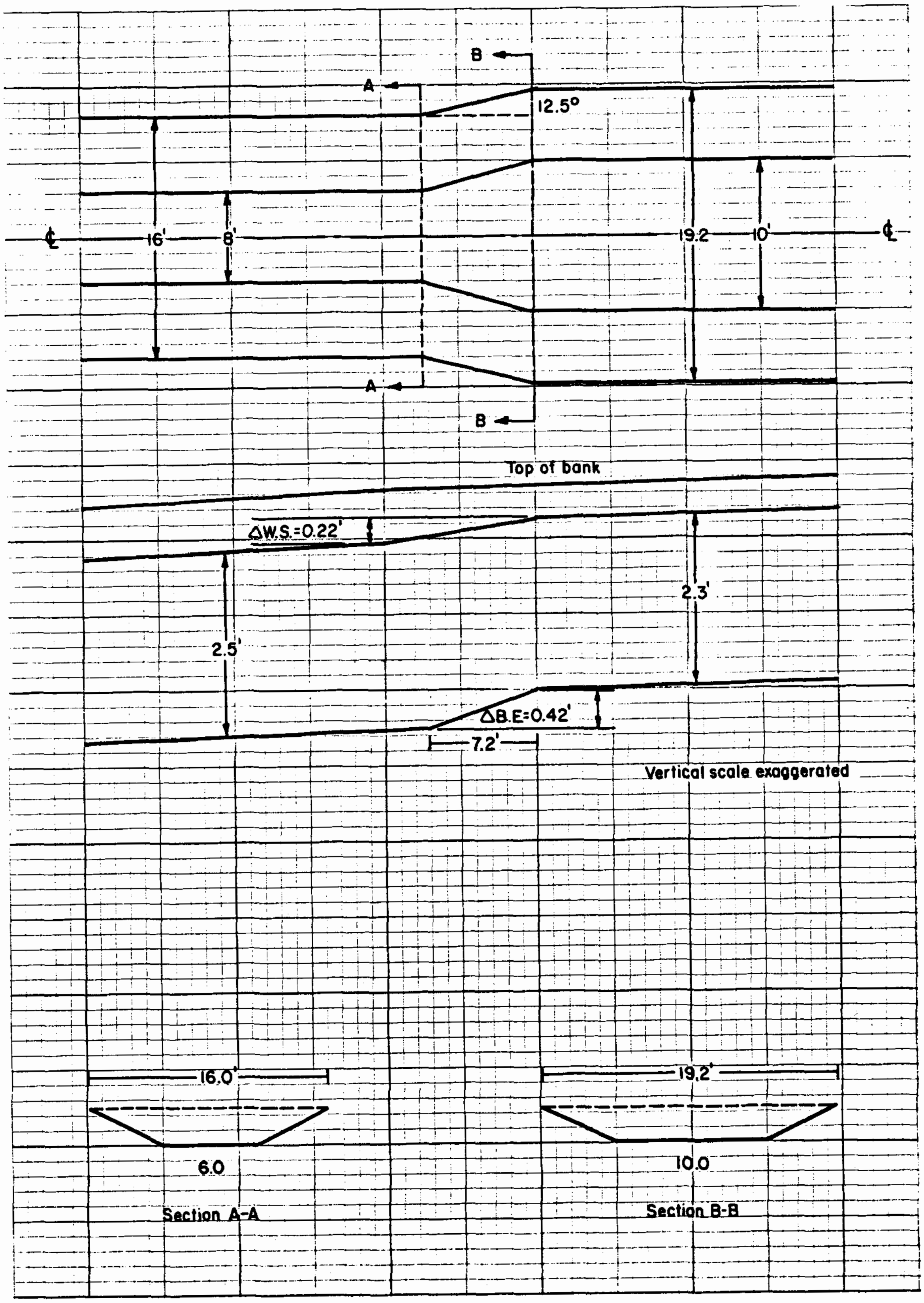

Figure 7.2. Converging transition design example.

7.8 References

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