Solution

Using Eq. 3.22 and Eq. 3.23, calculate the critical depth for a rectangular channel.

$$q = \frac{Q}{b} = \frac{50\ \frac{\text{ft}^3}{\text{sec}}}{10\ \text{ft}} = 5\ \text{ft}^3/\text{sec-ft}$$

$$d_c = \frac{q^{2/3}}{g^{1/3}} = \frac{\left(5\ \frac{\text{ft}^3}{\text{sec-ft}}\right)^{2/3}}{\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)^{1/3}} = 0.9\ \text{ft}$$

7. GRADUALLY VARIED FLOW

Gradually varied flow occurs in open channels in which the flow depth and velocity vary slowly from section to section. In contrast, rapidly varied flow undergoes swift changes in depth and velocity, such as the flow at a hydraulic jump over a spillway. Water surface depth profiles can be estimated for gradually varied flow using the normal depth, d_n, as calculated by the Manning equation; using the critical depth, d_c, from Eq. 3.23; using Eq. ~~3.30~~ 3.27 for the Froude number, Fr; or using the standard step method discussed in Sec. 3.10.

The *Froude number* in a rectangular channel can be estimated by

$$\text{Fr} = \frac{q}{\sqrt{g d_1^3}} \qquad 3.27$$

The *specific discharge* (flow rate), q, in a rectangular channel is calculated using Eq. 3.22. The depth of flow is d, and g is the gravitational acceleration.

Figure 3.9 describes typical water surface profiles for mild and steep channel slopes with gradually varied flow. Mild channel slope profiles M1, M2, and M3 are controlled by downstream water surface elevations. Steep channel slopes S1, S2, and S3 are controlled by upstream water surface elevations.

Example 3.18

The flow in a 10 ft wide, concrete, rectangular channel is 1900 ft^3/sec. The flow depth upstream is 12 ft, and the downstream flow is critical. The channel slope is 0.002 ft/ft. Determine the normal and critical depths, and estimate the type of water surface profile.

Solution

Determine the normal depth using trial and error and the Manning equation. Assume a normal depth, d_n, of 15 ft. Table 3.1 gives the Manning roughness coefficient of concrete as 0.013. From Eq. 3.7,

$$\begin{aligned} Q &= \left(\frac{1.49}{n}\right) A R^{2/3}\sqrt{S} \\ &= \left(\frac{1.49}{0.013}\right)(15\ \text{ft})(10\ \text{ft})\left(\frac{(15\ \text{ft})(10\ \text{ft})}{15\ \text{ft} + 10\ \text{ft} + 15\ \text{ft}}\right)^{2/3} \\ &\quad \times \sqrt{0.002\ \frac{\text{ft}}{\text{ft}}} \\ &= 1855\ \text{ft}^3/\text{sec} \end{aligned}$$

This is close enough to the known flow rate, so use a normal depth, d_n, of 15 ft.

Determine the critical depth from Eq. 3.22 and Eq. 3.23.

$$d_c = \frac{q^{2/3}}{g^{1/3}} = \frac{\left(\frac{Q}{b}\right)^{2/3}}{g^{1/3}} = \frac{\left(\frac{1900\ \frac{\text{ft}^3}{\text{sec}}}{10\ \text{ft}}\right)^{2/3}}{\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)^{1/3}} = 10.4\ \text{ft}$$

The normal depth of 15 ft is greater than the critical depth of 10.4 ft. Therefore, the flow is subcritical and mild. The depth at the upstream end, d_1, is 12 ft, which is greater than critical depth and less than normal depth. Therefore, $d_n > d_1 > d_c$, and the water surface profile type is mild at M2, as shown in Fig. 3.9.

8. HYDRAULIC JUMP

Hydraulic jump occurs when supercritical flow at high velocity abruptly transitions to subcritical flow at low velocity. This occurs when a steeply-sloped stream channel abruptly changes to a mild slope. The high velocity flow at lower depth transitions quickly to a low velocity flow at higher depth. Hydraulic jump commonly occurs at the base of dams or spillways, or at rapids or waterfalls along rivers and streams. Figure 3.10 describes the characteristics of hydraulic jump.