Simplified Accurate Solution for Design of Erodible Trapezoidal Channels

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Abstract: The sides and bottoms of earthen irrigation channels are erodible. The main design criterion for the earthen channel is to minimize or eliminate channel erosion under design flow conditions. The Manning formula and the tractive force equation were used as governing equations to design erodible and riprap channels. The traditional design approach involves a tedious trial procedure to find the bottom width of trapezoidal channels. Some hydraulic engineering problems require the solution of the bottom width from the Manning formula for nonerodible channels. An approximate equation is available for determining channel bottom width, but it is not applicable for channels with side slopes $z < 1$ (1 vertical and z horizontal), which are encountered in practice for nonerodible channels. This technical note presents a direct and accurate equation for determining the channel bottom width (with errors less than 0.1%) using the tractive force concept and a dimensionless form of the Manning formula. The proposed direct solution facilitates the design of erodible and riprap-lined channels. Moreover, the proposed equation can be used to accurately determine the bottom width of rigid (nonerodible) channels for any side slope. **DOI:** 10.1061/(ASCE)HE.1943-5584.0000385. © *2011 American Society of Civil Engineers.*

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Introduction

Trapezoidal open channels are used in many hydrology and hydraulic applications (Chow 1959; Chaudhry 2006; Haltas and Kavvas 2009; Wong and Zhou 2006). The channel design may be divided into two categories, depending upon whether the channel boundary is erodible or nonerodible (Prakash 2004). For erodible channels, the flow velocities are kept low so that the channel bottom and sides are not eroded. Erodible channels are generally less expensive than nonerodible linings, permit infiltration of water, and provide a more natural appearance.

There are two approaches to designing erodible channels: the permissible velocity approach and the permissible tractive force (boundary shear stress) approach. Under the permissible velocity approach, which is empirical, the channel is assumed to be stable if the mean velocity is lower than the maximum permissible velocity. The tractive force approach focuses on stresses developed at the interface between the flowing water and material forming the channel boundary. By definition, the permissible tractive force is the maximum unit tractive force that will not cause serious erosion of the channel bed material (Chow 1959). The permissible velocity approach has been used to design numerous stable channels in the United States and throughout the world. However, considering the actual physical processes occurring in open-channel flow, the permissible tractive force approach, which has a theoretical basis, is considered a more realistic model for erosion processes for erodible channels (Kilgore and Cotton 2005).

The tractive force concept principally originates from work carried out by the U.S. Bureau of Reclamation (Raudkivi 1990; HR Wallingford 1992). The flow in a channel exerts tractive forces (shear stresses) on the channel bed that are equal in magnitude, but opposite in direction to the friction forces produced by the channel bed (Akan 2006). The tractive force tends to move the particles on the channel bed in the flow direction. Erosion will occur if the shear forces exceed the resistive forces, preventing the movement of these particles. When used for the design of earthen (or riprap) channels, the method proportions the channel section so that the particles will not move under the design flow conditions.

The maximum tractive force caused by the flow on the bottom and sides of trapezoidal channels depends on a coefficient that is a function of the bottom width to flow depth ratio (b/y) and the channel side slopes (Chow 1959; French 1985; Akan 2001). This requires a tedious trial procedure, since the ratio (b/y) is initially unknown. Chaudhry (2006) has considerably simplified the trial procedure by using single, limiting values for the coefficient that is required for determining the maximum tractive force. A similar approach has also been developed by Kilgore and Cotton (2005) for channels with flexible linings. In their simplified approach, the design depth is determined explicitly. However, a trial solution is still needed to find the bottom width from the Manning formula. Akan (2001) presented a chart that facilitated the sizing of erodible channels, along with an approximate, explicit equation for determining the channel bottom width. However, his equation is not applicable for side slopes $z < 1$, for accuracy reasons.

This technical note presents a direct and accurate equation for determining the channel bottom width (with errors $< 1\%$) for erodible and riprap-lined channels based on the tractive force concept. The following sections present the formula for determining the limiting flow depth that is needed for erodible channels, followed by the proposed direct equation for determining the channel bottom

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