

SHEAR STRESS

Key to Channel Erosion Protection

The design of hydraulically stable storm water drainage channels is a key element of most civil engineering projects. The ability to collect, contain, and convey storm water until it leaves the job site, without creating significant erosion, requires a thorough engineering analysis.

Hydraulically stable channels are vital to assure that adjacent capital improvements on the site are not damaged by erosion. They are also needed to ensure that the regulatory requirements regarding water Quality and construction site storm water discharge are being met.

Generally accepted engineering practice uses shear stress as the key parameter for determining the hydraulic stability of a storm water drainage channel.



DEFINITION

Shear stress is the force applied by flowing liquid to its boundary. In this case, the liquid is storm water and the boundary is the channel surface. Shear stress is also occasionally referred to as the “tractive force.” Put simply, shear stress describes the force of water that is trying to drag the channel surface downstream with it.

THEORY

Shear stress is calculated based on the principle of conservation of momentum.

MATHEMATICS

For non-uniform flow conditions, the shear stress equation is complex to account for the changes in the depth over a given length; however, for the uniform flow conditions found on many storm water drainage channels, the complex equation can be simplified to the following formula:

$$\tau = \gamma \times d \times S$$

Where,

τ = shear stress, Pa (lb/ft²)

γ = unit weight of water, N/m³ (lb/ft³)

d = depth of flow, m (ft)

S = energy gradient, m/m (ft/ft)

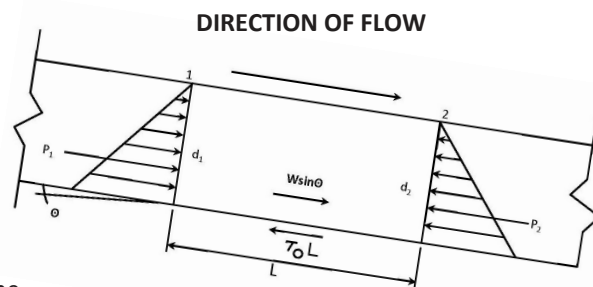
For most open channel flow conditions, the energy gradient is Parallel to the channel bottom. Therefore, the bed slope of the channel can be substituted for the energy gradient.

If non-uniform flow conditions are present (i.e. accelerating or decelerating flow) or if channel cross section changes are encountered, a more sophisticated analysis will be required. Special attention needs to be given to hydraulic structures, such as bridges and culverts. For most cases, the above equation is applicable.

APPLICATION

When calculating shear stress, the standard unit weight of the water is generally used 9,806 N/m³ (62.4 lb/ft³). This unit weight is for clear water in standard atmospheric conditions. In reality, most storm water discharges have a slightly higher unit weight due to the mass of suspended solids. The unit weight should be increased accordingly if significant suspended solids are likely.

The shear stress equation can be used to calculate the value at any given depth. For most applications though, the critical (i.e. maximum) stress is the key criteria. Therefore, the maximum depth of flow should be used.



If a stepped channel lining is desired, the maximum shear stress for each zone can be calculated based on the respective maximum depth for that zone. For larger channels, a zonal approach may provide cost savings since the higher performance (and generally more costly) solutions are used only where warranted. To accurately determine the overall flow depth, it is also necessary use the appropriate Manning's n -value for each zone.

For straight channels, the critical shear stress is the same across the width of the channel bottom; however, if the channel curves the shear stress will be higher on the outside of the bend as compared to the inside. This is analogous to the centrifugal force one feels in an automobile that is turning a corner: the sharper the bend - the greater the effect, and visa versa.

The increase in shear stress from the straight conditions can be significant depending on the severity of the bend. This increase is inversely related to the channel curvature and bottom width, and it is detailed in FHWA HEC-15 (Chen and Cotton, 1986).

K_b is a function of R_c / B

Where,

K_b = Bend coefficient, unitless

R_c = radius of curvature, m (ft)

B = bottom width, m (ft)

In a qualitative sense, K can be approximated, as follows:

Straight reach	1.0
Mild meanders	1.1 to 1.4
Looping meanders	1.5 to 1.8
Sharp turns	1.9 to 2.1

SIGNIFICANCE

Shear stress is a better predictor of erosion potential than velocity, because it considers the actual force of the water on the boundary of the channel. As an analogy, if two vehicles are both traveling about 95km/hr (60mph) and are about to crash a rough idea of their damage potential is provided. If, however, the description further identifies one vehicle as a passenger car and the other as a semi-truck, a much better indication of the damage potential results. The same can be said for shear stress and the erosion potential of the flowing water.

EXAMPLE

A perimeter storm water drainage channel on a large landfill has been evaluated using Manning's equation for a 100-year event. An n -value of 0.035 was used based on the initial use of a biocomposite reinforcing mat and ultimately a permanently reinforced grass-lined channel. The channel has a trapezoidal cross-section, uniform flow conditions, a bed slope of 3% and two mild bends. The maximum depth of flow was found to be 1.0 m (3.25 ft). What is the critical shear stress?

For the straight reaches, the shear stress is:

$$\begin{aligned}\tau &= \gamma \times d \times S \\ 9,806 \text{ N/m}^3 \times 1.0 \text{ m} \times 0.03 \\ 294 \text{ N/m}^3 \text{ (or 0.29 kPa)}\end{aligned}$$

On the outside of the bends, the shear stress is:

$$\begin{aligned}\tau &= 0.29 \text{ kPa} \times 1.25 \\ 0.37 \text{ kPa}\end{aligned}$$

CHANNEL LINING OPTIONS

The following general guidance is provided for designs, based on approximate shear stress limits:

Vegetation (unreinforced)	147 Pa (3 psf)
Erosion Control Blanket	147 Pa (3 psf)
Rip-Rap [(D_{50} = 46 cm (8 in))]	294 Pa (6 psf)
Bio-Composite Reinforced Mat	392 Pa (8 psf)
Rip-Rap [(D_{50} = 61 cm (24 in))]	392 Pa (8 psf)
Turf Reinforcement Mat	392 Pa (8 psf)
Gabions	392 Pa (8 psf)
Articulated Concrete Block	735 Pa (15 psf)
Fabric-Formed Concrete	980 Pa (20 psf)

WORKS CITED

Chen, Y.H. and G.K. Cotton. 1986. "Design of Roadside Channels with Flexible Linings." Hydraulic Engineering Circular No. 15, Report No. FHWA-IP-86-5. Washington, D.C., Federal Highway Administration.

