Erosion and Sediment Control Design:

Session 2 – Channel and Slope Surface Stability

ENVIRONMENTAL, STORMWATER, AND RIGHT-OF-WAY TRAINING

DECEMBER 10, 2014

Channel and slope surface stability

Focus on selecting a rolled erosion control product (RECP) for use in channels and on slopes

Two types of RECPs:

- Erosion control blankets (ECB)
- Turf reinforcement mats (TRM)

RECP manufacturers typically provide design data and recommendations for their products

Index Value Properties:

Property	Test Method	Typical
Thickness	ASTM D6525	0.31 in (7.87 mm)
Resiliency	ECTC Guidelines	82%
Water Absorbency	ASTM D1117	220%
Mass/Unit Area	ASTM 6475	8.00 oz/yd^2 (271 g/m^2)
Swell	ECTC Guidelines	13%
Smolder Resistance	ECTC Guidelines	Yes
Stiffness	ASTM D1388	0.75 oz-in
Light Penetration	ECTC Guidelines	6.6%
Tensile Strength –MD	ASTM D6818	294 lbs/ft (4.36 kN/m)
Elongation – MD	ASTM D6818	21.3%
Tensile Strength – TD	ASTM D6818	205.2 lbs/ft (3.04 kN/m)
Elongation – TD	ASTM D6818	28.4%

Performance Design Values:

Maximum Permissible Shear Stress	
Unvegetated Shear Stress	2.25 lbs/ft^2 (108 Pa)
Unvegetated Velocity	10.00 ft/s (3.05 m/s)

Slope Design Data: C Factors			
	Slope Gradients (S)		
Slope Length (L)	≤ 3:1	3:1 – 2:1	≥ 2:1
≤ 20 ft (6 m)	0.001	0.029	0.082
20-50 ft	0.036	0.060	0.096
≥ 50 ft (15.2 m)	0.070	0.090	0.110

Roughness Coefficients- Unveg.	
Flow Depth	Manning's n
≤ 0.50 ft (0.15 m)	0.022
0.50 – 2.0 ft	0.022 – 0.014
≥ 2.0 ft (0.60 m)	0.014

Channel stability

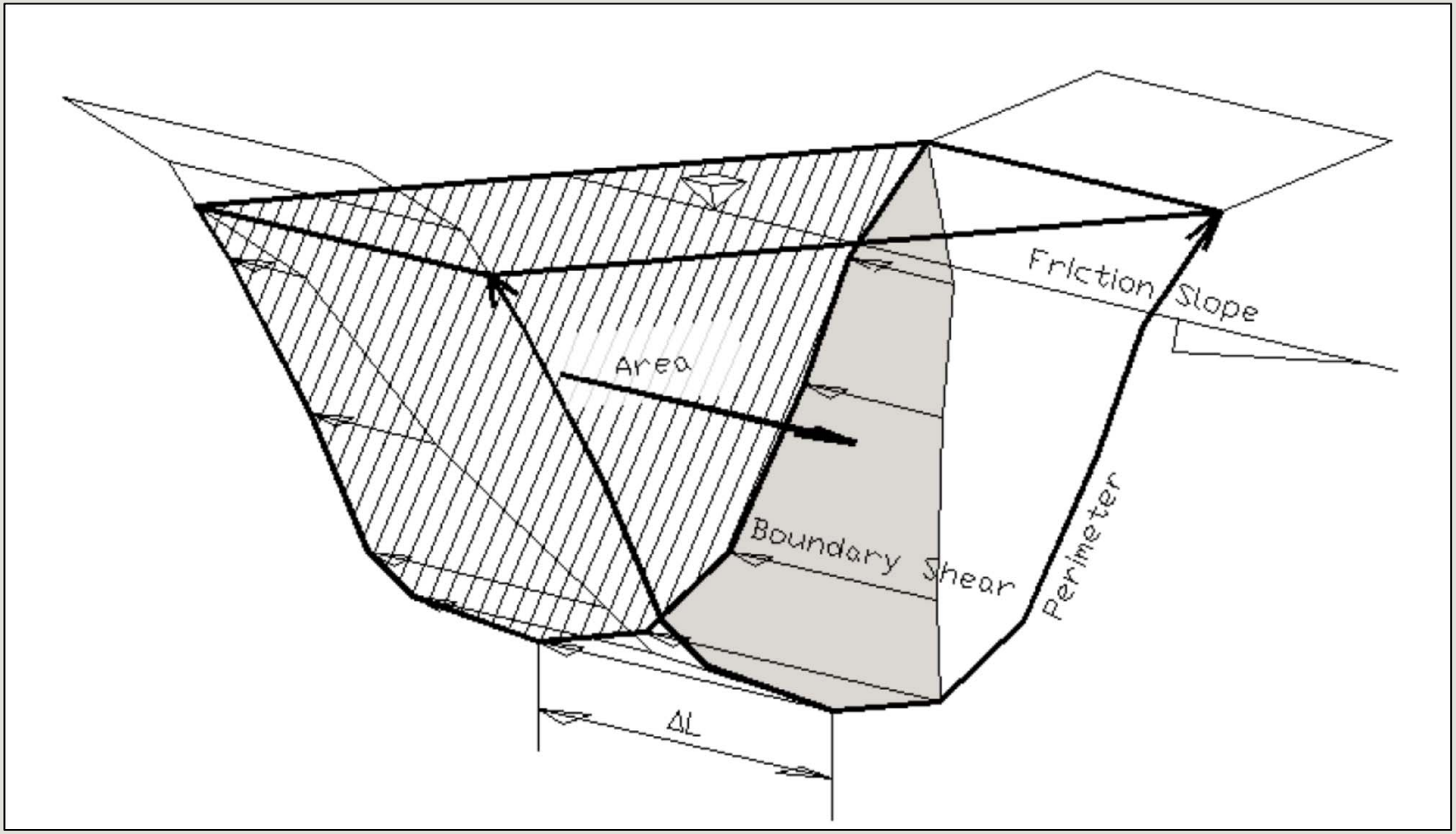
Channel stability design:

- Permissible velocity
- Allowable tractive force (shear stress)

Channel stability

Allowable shear stress design steps:

1. Obtain flow rate, Manning's n, and channel dimensions
2. Calculation of flow depth, d
3. Calculate maximum shear stress, τ_d
4. Compare maximum shear stress with allowable shear stress



Source: NRCS (1986). *Urban Hydrology for Small Watersheds*. USDA Soil Conservation Service, TR-55, 156 pgs.

Channel stability

Design shear stress:

$$\tau_d = \gamma d s$$

Where,

τ_d = shear stress in channel at maximum depth (design stress) (lb/ft^2)

γ = unit weight of water (62.4 lb/ft^3)

d = depth of flow in channel (ft)

s = channel slope (ft/ft)

Channel stability

Permissible soil shear stress, $\tau_{p,soil}$ (noncohesive soils):

If D_{75}<0.05 in., $\tau_{p,soil} = 0.02$ lb/ft^2

If $0.05 < D_{75} < 2$ in., $\tau_{p,soil} = 0.4(D_{75})$ lb/ft^2

Channel stability

Permissible soil shear stress (cohesive soils):

$$\tau_{p,soil} = (c_1 PI^2 + c_2 PI + c_3)(c_4 + c_5 e)^2 c_6$$

Where,

$\tau_{p,soil}$= permissible shear stress on the soil surface (lb/ft^2)

PI= plasticity index

e= void ratio

$c_1, c_2, c_3, c_4, c_5, c_6$= coefficients

Coefficients for permissible soil shear stress								
ASTM Soil Classification	**Typical names**	**Applicable Range**	**c1**	**c2**	**c3**	**c4**	**c5**	**c6**
GM	Silty gravels, gravel-sand silt mixtures	$10 \leq PI \leq 20$	1.07	14.3	47.7	1.42	-0.61	1×10^{-4}
		$20 < PI$	0.0	0.0	0.076	1.42	-0.61	1.0
GC	Clayey gravels, gravel-sand-clay mixtures	$10 \leq PI \leq 20$	0.0477	2.86	42.9	1.42	-0.61	1×10^{-3}
		$20 < PI$	0.0	0.0	0.119	1.42	-0.61	1.0
SM	Silty sands, sand-silt mixtures	$10 \leq PI \leq 20$	1.07	7.15	11.9	1.42	-0.61	1×10^{-4}
		$20 < PI$	0.0	0.0	0.058	1.42	-0.61	1.0
SC	Clayey sands, sand-clay mixtures	$10 \leq PI \leq 20$	1.07	14.3	47.7	1.42	-0.61	1×10^{-4}
		$20 < PI$	0.0	0.0	0.076	1.42	-0.61	1.0
ML	Inorganic silts, very fine sands, silty or clayey fine sands	$10 \leq PI \leq 20$	1.07	7.15	11.9	1.48	-0.57	1×10^{-4}
		$20 < PI$	0.0	0.0	0.058	1.48	-0.57	1.0
CL	Inorganic clays of low to medium plasticity (lean clays)	$10 \leq PI \leq 20$	1.07	14.3	47.7	1.48	-0.57	1×10^{-4}
		$20 < PI$	0.0	0.0	0.076	1.48	-0.57	1.0
MH	Inorganic silts, elastic silts	$10 \leq PI \leq 20$	0.0477	14.3	10.7	1.38	-0.373	1×10^{-3}
		$20 < PI$	0.0	0.0	0.058	1.38	-0.373	1.0
CH	Inorganic clays of high plasticity (fat clays)	$20 < PI$	0.0	0.0	0.097	1.38	-0.373	1.0

Source: Temple, D. M., Robinson, K. M., Ahring, R. M., and Davis, A. G. (1987). Stability design of grass-lined open channels. *USDA Ag. Handbook 667*, 176 pp. and Kilgore, R. T. and Cotton, G. K. (2005). Design of roadside channels with flexible linings. *FHWA-NHI-05-114 Hydraulic Engineering Circular Number 15, 3rd Edition*, 153 pp.

Typical Permissible Shear Stresses		
Lining Category	**Lining Type**	**Permissible Shear Stress (lb/ft^2)**
Bare soil – Cohesive (PI = 10 and e = 0.5)	Clayey sands	0.037 – 0.095
	Inorganic silts	0.027 – 0.11
	Silty sands	0.024 – 0.072
Bare soil – Cohesive (PI > 20 and e = 0.5)	Clayey sands	0.094
	Inorganic silts	0.083
	Silty sands	0.072
	Inorganic clays	0.14
Bare soil – Non-cohesive (PI < 10)	D_{75} < 0.05 in	0.02
	D_{75} = 0.3 in	0.12
	D_{75} = 0.6 in	0.24
Riprap	D_{50} = 6 in	2.4
	D_{50} = 12 in	4.8

Source: Kilgore, R. T. and Cotton, G. K. (2005). Design of roadside channels with flexible linings. *FHWA-NHI-05-114 Hydraulic Engineering Circular Number 15, 3rd Edition*, 153 pp.

Channel stability

Kilgore and Cotton method (HEC-15):

– Initial construction (unvegetated state)

$$\tau_{p,RECP} = \frac{\tau_{d,RECP}}{0.14}\left(\tau_{p,soil} + \frac{0.14}{4.3}\right)$$

Where,

$\tau_{p,RECP}$ = permissible shear stress on the RECP/soil (lb/ft^2)

$\tau_{d,RECP}$ = manufacturer's design permissible shear stress for the RECP (lb/ft^2)

Channel stability

ECBs and TRMs:

- Compare permissible shear stress on the RECP/soil with design stress

$$\tau_{p,RECP} \geq SF\tau_d$$

- Should also evaluate channel under partially and fully vegetated condition

Slope surface stability

Design steps:

1. Determine flow depth on slope
2. Calculate maximum shear stress on slope
3. Calculate effective shear stress on the soil
4. Determine minimum Manning's roughness needed
5. Determine maximum *C* value

Slope surface stability

Sheetflow depth:

$$y = \left(\frac{qn}{1.49s^{0.5}}\right)^{3/5}$$

Where,

y = sheetflow depth (ft)

q = unit width flow rate (Q/W: the total flow rate, divided by the slope width in ft)

n = sheet flow roughness coefficient for a fully vegetated slope surface

s = slope (ft/ft)

Slope surface stability

Sheetflow shear stress:

$$\tau_d = \gamma y s$$

Where,

τ_d = maximum shear stress on slope (lb/ft^2)

γ = unit weight of water (62.4 lbs/ft^3)

y = sheetflow depth (ft)

s = slope (ft/ft)

Slope surface stability

Effective shear stress on the soil:

$$\tau_e = \tau_d\left(1 - C_f\right)\left(\frac{n_s}{n}\right)^2$$

Where,

τ_e= effective shear stress on the soil surface (lb/ft^2)

τ_d= design shear stress (lb/ft^2)

C_f= grass cover factor

n_s= soil grain roughness

n = overall lining roughness

Slope surface stability

Soil grain roughness:

$n_s = 0.0155$ for fine grained soils (D_{75}<0.05 in)

$n_s = 0.026(D_{75})^{1/6}$ for all non-cohesive soils with $D_{75} \geq 0.05$ in

Slope surface stability

Manning's roughness of RECP (minimum):

$$n_{RECP,min} = n_s \sqrt{\frac{\tau_d\left(1 - C_f\right)}{\tau_{p,Soil}}}$$

Blankets and mats that have an n value greater than $n_{RECP,min}$ are candidates for use

- C_f is 0 for unvegetated slope protected by RECP

Slope surface stability

A maximum *C* factor for the RECP is calculated for the slope for 0.25 inches of uniform soil loss

$$C_{RECP,max} = \frac{0.25}{\frac{1}{1.815\gamma_{soil}} R(K)(LS)(P)}$$

Where,

$C_{RECP,max}$ = maximum *C* factor for RECP

γ_{soil} = slope soil unit weight (lbs/ft^3)

R, K, LS, P = *RUSLE* factor values for slope

RECP Selection

RECP Design considerations:

- Application (channel, slope)
- Longevity
- Constructability
- Maintenance