Module 5

Channel and Slope Stability for Construction Site Erosion Control

by

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July 19, 2007

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1.0 Introduction

1.1 Summary

This document describes the design of swale for the site including the suitable selection of lining for the channel as well as the slope stability control.

1.2 Objectives

The objective of this document is to design the swale for the site as well as making a suitable plan for the slope protection.

2.0 Introduction and Hydrology

2.1 Hydrology

Campus Derive Relocation Project is planted at the University of Alabama Campus on Campus Drive between Hackberry and Jefferson Avenue. The nearby receiving water, Black Warrior River is located north of the construction site. Runoff is planned to collect to the creek locating at the north of the construction site and delivered to the Black Warrior River. Figure 5 shows sub-drainages for the upslope, down-slope, and on-site areas for the construction site. Red line indicates the watershed area for the site and the pink line subdivides them into upstream (U1-U4), onsite (O1-O5), and downstream (D1) areas. Blue line shows the flow pass for the area. The watershed area has approximately 63 acres.

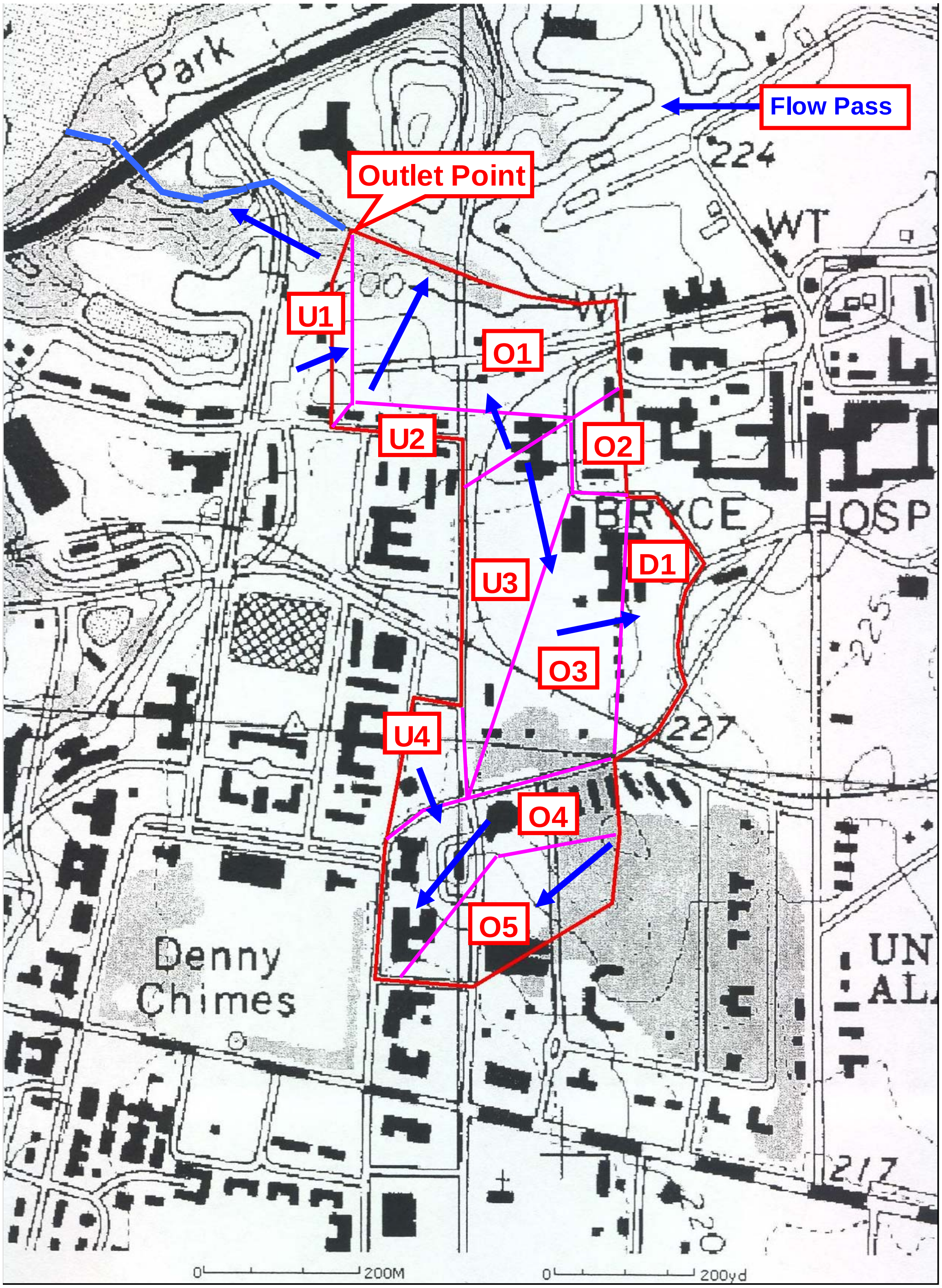


Figure 1: Watershed for the site (source: TerraServer)

3.0 Channel design calculation

The site consists of one main channel that diverts water from the upper portion of the watershed. The channel is located at the north side of the watershed area of the construction site. The cross section of the channel will be a trapezoidal in shape as shown in Figure 2.

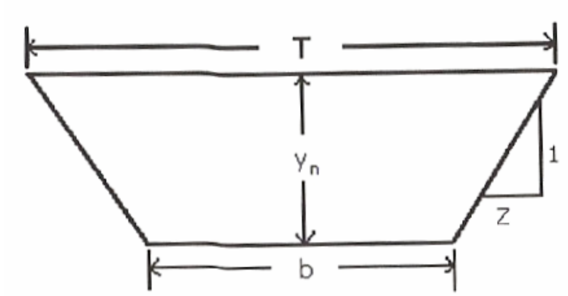


Figure 2: Cross section of the channel

The soil at the site is identified as sandy loam by Tuscaloosa County Soil Survey and the design criteria for the channel is as follows.

Maximum permissible velocity (V_{max}): 2.5 ft/sec
Allowable shear stress (τ_0): 0.075 lb/ft^2

Sandy loam soil have the manning's coefficient is 0.02. Manning's equation for open channel flow will be used to compute the hydraulic radius.

$$AR^{2/3} = \frac{nQ}{1.49S^{0.5}}$$

$$A = \frac{Q}{V} = (b + Zy)y$$

$$P = b + Zy$$

$$A = Q/V = (b + Zy)y$$

$$P = b + Zy\sqrt{1 + Z^2}$$

where,
R = hydraulic radius, ft
V= permissible velocity, ft/sec
S = channel slope, ft/ft
n = roughness of channel lining material, dimensionless
P= wetted parameter
Z= slope
A= area

All the required geometry calculations were performed by using excel spread sheet. Table 1 describes the channel design and lining selection.

Table 1: Channel design and lining selection

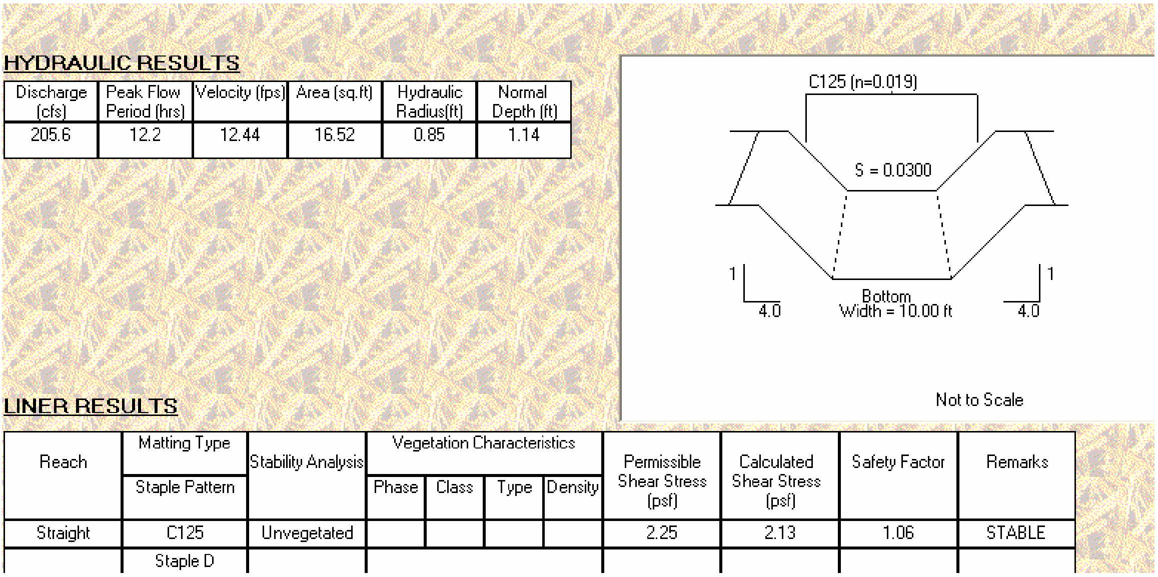
Channel ID	Q (ft^3/s)	S_0	$nQ/1.49S_0^{1/2}$	b (ft)	z	y (ft)	A (ft^2)	P (ft)	R (ft)	$AR^{2/3}$	V_{max} (ft/s)	τ_0 (lb/ft^2)	Need lining?	Type of lining	Allowable τ_0 (lb/ft^2)
U1	10.60	0.133	0.390	6	1	0.19	1.206	6.551	0.184	0.390	8.791	1.619	Yes	C125BN	2.35
U2	15.90	0.028	1.285	6	1	0.40	2.550	7.127	0.358	1.285	6.235	0.686	Yes	C125BN	2.35
U3	20.69	0.023	1.823	6	1	0.49	3.191	7.390	0.432	1.823	6.484	0.712	Yes	C125BN	2.35
U4	16.57	0.018	1.649	6	1	0.46	2.992	7.309	0.409	1.649	5.539	0.526	Yes	C125BN	2.35
O1	205.59	0.050	12.341	6	1	1.53	11.488	10.317	1.113	12.341	17.896	4.762	Yes	P300	8.00
O2	143.28	0.089	6.450	6	1	1.04	7.354	8.953	0.821	6.450	19.483	5.791	Yes	P300	8.00
O3	138.53	0.011	17.649	6	1	1.88	14.768	11.304	1.306	17.649	9.380	1.299	Yes	C125BN	2.35
O4	87.68	0.047	5.423	6	1	0.94	6.541	8.665	0.755	5.423	13.404	2.769	Yes	P300	8.00
O5	32.58	0.080	1.546	6	1	0.45	2.870	7.260	0.395	1.546	11.351	2.223	Yes	C125BN	2.35

Channel ID	Q (ft^3/s)	S_0	$nQ/1.49S_0^{1/2}$	b (ft)	z	y (ft)	A (ft^2)	P (ft)	R (ft)	$AR^{2/3}$	V_{max} (ft/s)	τ_0 (lb/ft^2)	Need lining?	Type of lining	Allowable τ_0 (lb/ft^2)
U1	10.60	0.133	0.390	10	1	0.14	1.451	10.404	0.139	0.390	7.308	1.190	Yes	SC150BN	2.10
U2	15.90	0.028	1.285	10	1	0.29	3.014	10.828	0.278	1.285	5.275	0.504	Yes	SC150BN	2.10
U3	20.69	0.023	1.823	10	1	0.36	3.744	11.022	0.340	1.823	5.526	0.523	Yes	SC150BN	2.10
U4	16.57	0.018	1.649	10	1	0.34	3.518	10.962	0.321	1.649	4.710	0.386	Yes	SC150BN	2.10
O1	205.59	0.050	12.341	10	1	1.14	12.686	13.221	0.960	12.341	16.206	3.553	Yes	P300	5.50
O2	143.28	0.089	6.450	10	1	0.77	8.319	12.184	0.683	6.450	17.224	4.284	Yes	P300	5.50
O3	138.53	0.011	17.649	10	1	1.41	16.081	13.987	1.150	17.649	8.614	0.976	Yes	SC150BN	2.10
O4	87.68	0.047	5.423	10	1	0.70	7.443	11.968	0.622	5.423	11.780	2.045	Yes	SC150BN	2.10
O5	32.58	0.080	1.546	10	1	0.33	3.380	10.926	0.309	1.546	9.639	1.634	Yes	SC150BN	2.10

Channel ID	Q (ft^3/s)	S_0	$nQ/1.49S_0^{1/2}$	b (ft)	z	y (ft)	A (ft^2)	P (ft)	R (ft)	$AR^{2/3}$	V_{max} (ft/s)	τ_0 (lb/ft^2)	Need lining?	Type of lining	Allowable τ_0 (lb/ft^2)
U1	10.60	0.133	0.390	10	4	0.14	1.492	11.165	0.134	0.390	7.105	1.175	Yes	S75	1.55
U2	15.90	0.028	1.285	10	4	0.29	3.178	12.352	0.257	1.285	5.004	0.491	Yes	S75	1.55
U3	20.69	0.023	1.823	10	4	0.35	3.987	12.884	0.309	1.824	5.190	0.506	Yes	S75	1.55
U4	16.57	0.018	1.649	10	4	0.33	3.735	12.721	0.294	1.650	4.437	0.375	Yes	S75	1.55
O1	205.59	0.050	12.341	10	4	1.03	14.503	18.475	0.785	12.341	14.176	3.207	Yes	P300	5.50
O2	143.28	0.089	6.450	10	4	0.72	9.261	15.931	0.581	6.451	15.472	3.990	Yes	P300	5.50
O3	138.53	0.011	17.649	10	4	1.25	18.653	20.268	0.920	17.649	7.427	0.862	Yes	S75	1.55
O4	87.68	0.047	5.423	10	4	0.65	8.229	15.381	0.535	5.423	10.655	1.918	Yes	SC150BN	2.10
O5	32.58	0.080	1.546	10	4	0.32	3.581	12.620	0.284	1.547	9.097	1.586	Yes	SC150BN	2.10

Note: Highlighted graph indicate the selected channels for the site.

The table indicates that all channels require the lining in order to satisfy the shear stress requirement. Also, Figure 3 shows the channel design and lining selection by North American Green software.



HYDRAULIC RESULTS

Discharge (cfs)	Peak Flow Period (hrs)	Velocity (fps)	Area (sq.ft)	Hydraulic Radius(ft)	Normal Depth (ft)
205.6	12.2	12.44	16.52	0.85	1.14

LINER RESULTS

Reach	Matting Type / Staple Pattern	Stability Analysis	Vegetation Characteristics: Phase	Class	Type	Density	Permissible Shear Stress (psf)	Calculated Shear Stress (psf)	Safety Factor	Remarks
Straight	C125	Unvegetated					2.25	2.13	1.06	STABLE
	Staple D									

Figure 3: Channel design and lining selection by North American Green software

4.0 Slope protection

The site is divided into upstream, onsite, and downstream areas. The slope of the site is categorized into four types including: slope <2.0%, slope 2-5%, slope 5-10%, and slope >10%. The peak flow rates for individual watershed areas were calculated using the WinTR-55. Manning's n is 0.02 for the sandy loam as described above. The site has mainly two work phases and it will require the slope protection for the active construction sites during the construction and between these work phases. Onsite 3 is chosen to perform the slope protection analysis, having the following characteristics.

Slope (So) = 11%
Width of slope (W) = 150 ft
Flowrate (Q) = 18.88 cfs
q = Q/W = 0.126 cfs/ft
Manning's coefficient (n) = 0.02

Manning's equation is used to calculate the nominal depth for a sheetflow as follows.

$$y = \left(\frac{qn}{1.49s^{0.5}}\right)^{3/5} = \left(\frac{0.126 \times 0.02}{1.49 \times 0.16^{0.5}}\right)^{3/5} = 0.0421\,ft$$

Where:
y = the flow depth (in feet),
q = the unit width flow rate (Q/W)
n = the sheet flow roughness coefficient for the slope surface
s = the slope (as a fraction)

The corresponding maximum shear stress is calculated as follows.

$$\tau_0 = \gamma y s = 62.4 \times 0.0421 \times 0.11 = 0.289 lb/ft^2$$

where:
γ = specific weight of water (62.4 lbs/ft3)
y = flow depth (ft)
S = slope (ft/ft)

The allowable shear stress (τ_0) is 0.075 lb/ft^2. Thus, it is necessary to install the vegetated mat in order to satisfy the stress requirement. The effective shear stress impacting the soil underneath an erosion control mat is calculated as follows.

$$\tau_e = \tau_0 (1 - C_f) \left(\frac{n_s}{n} \right)^2$$

$$0.075 = 0.289(1-0)\left(\frac{0.02}{n_{mat}} \right)$$

$$n_{mat} = 0.077$$

Where,
τ_e = effective shear stress exerted on soil beneath mat on slope
τ_o = maximum shear stress from the flowing water = 0.289 lbs/ft2
C_f = vegetal cover factor (this factor is 0 for an unvegetated channel) = 0 for critical unvegetated slope
n_s = roughness coefficient of underlying soil = 0.02
n_{mat} = roughness coefficient of mat

The final mat selection can be selected by applying the RUSLE.

$$A = (R)(K)(LS)(C)(P) = 375 \times 0.32 \times 6.65 = 798 tons/acre/year$$

Where,
R = 375 (Tuscaloosa, Alabama)
K = 0.32
LS = 6.65 for length of 725 ft and slope of 11%
C = 1 for bare slope

The total soil loss is 798 tons/acre/year or 4.75 inches per year. The maximum allowable erosion loss is 0.25 to 0.5 inches/year. The required C factor is from 0.25/4.75 to 0.5/4.75, which rages 0.053 to 0.11.
The C125 mat has a C of 0.09 (intermediate in the above range) and an n of 0.022 for this slope and condition.
The mat n is 0.022 and it cannot satisfy the required n value of 0.077. Thus, it requires terraces to divide the slope into several segments, and use diversion drains in order to collect the water from each terrace bench. Assume to divide slope into two parts (362.5 ft each) which enable the flowrate of Q to be half of the original as well as the flow depth of q to be half.

$$y = \left(\frac{qn}{1.49 s^{0.5}} \right)^{3/5} = \left(\frac{0.063 \times 0.02}{1.49 \times 0.16^{0.5}} \right)^{3/5} = 0.0248\, ft$$

The resulting share stress is calculates as follows.

$$\tau_0 = \gamma y s = 62.4 \times 0.0248 \times 0.11 = 0.170 lb / ft^2$$

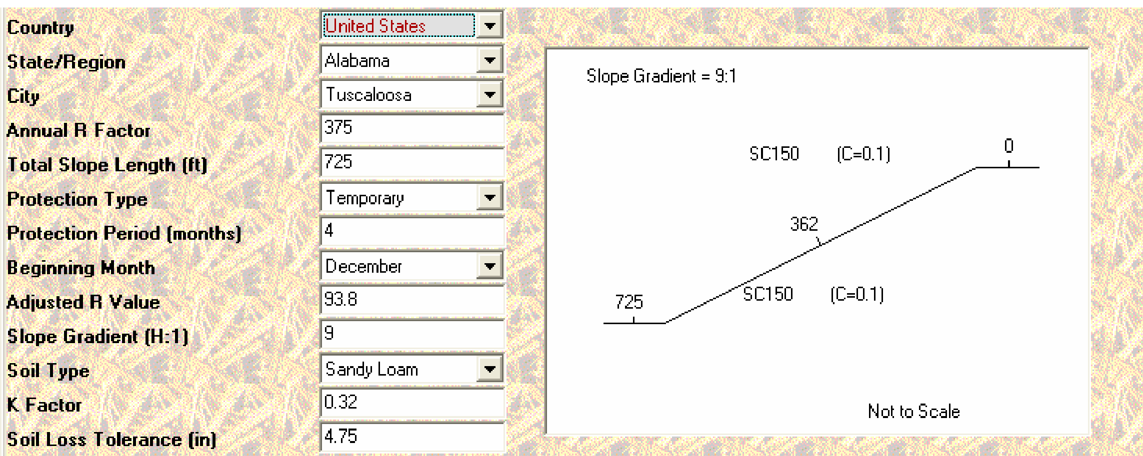
The required value for n is as follows.

$$\tau_e = \tau_0 (1 - C_f) \left(\frac{n_s}{n} \right)^2$$

$$0.075 = 0.289 (1 - 0) \left(\frac{0.02}{n_{mat}} \right)$$

$$n_{mat} = 0.045$$

The SC150 mat has a C of 0.11 (intermediate in the above range) and an n of 0.055 for this slope and condition therefore this mat is selected for the slope protection.
Also, Figure 4 shows the slope selection calculated by North American Green software.



Reach	Cum. Dist. Begin (ft)	Cum. Dist. End (ft)	Material	Vegetation Type Growth Habit	Density	ASL bare (in)	ASL mat (in)	MSL bare (in)	MSL mat (in)	SLT (in)	SF	Remarks	Staple
1	0	362	SC150			0.738	0.074	1.207	0.121	4.75	39.340	STABLE	C
2	362	725	SC150			1.654	0.165	1.958	0.196	4.75	24.254	STABLE	C
3													
	0	725		Composite		1.197	0.120						

Figure 4: Slope protection by North American Green software