GRASS LINED CHANNEL DESIGN EXAMPLE USING HEC-15

Given the following channel geometry, soil conditions, grade, and design flow, determine if a grass lining that will be maintained in good condition in the spring and summer months (the main storm seasons) is an acceptable channel liner.

Given:

Geometry: Triangular (V-ditch), B = 0.0 ft, Z = 4

Soil: Clayey sand (SC classification)

PI = 16

e = 0.35

Soil Type: Cohesive

Grass: Vegetation Type: Turf

Retardance Class: Type C

Grass Height, h = 0.67 ft

Grass Condition: Good

Grass Density-Stiffness Coefficient, C_s, = 9.0

Slope: 2.0 percent

Flow: 15 ft^3/s

Solution:

Use the procedure in Section 3.1, HEC-15 for a straight channel.

Step 1. Channel slope, soil type, geometry, and discharge are given.

Step 2. Assume an initial depth = 1.0 ft.

From the geometric relationship of a trapezoid (see HEC-15, Appendix B):

A (Area) = $Bd + Zd^2 = 0.0(1.0) + 4(1.0)^2 = 4.00\ ft^2$

P (Wetted Perimeter) = $B + 2d(Z^2 + 1)^{1/2} = 0.0 + 2(1.0)(4^2 + 1)^{1/2} = 8.25$ ft

R (Hydraulic Radius) = A/P = (4.00)/(8.25) = 0.485 ft

Step 3. To estimate n, determine the applied shear stress on the grass lining and the discharge:

$\tau_o = \gamma R S_o = 62.4(0.485)(0.02) = 0.61\ lb/ft^2$ (Refer to FDM 13-30-10, Equation 2)

Determine a Manning's n from FDM 13-30-15, Equation 12 with

$C_n = 0.237(C_s)^{0.1}(h)^{0.528} = 0.237(9.0)^{0.1}(0.67)^{0.528} = 0.238$ (HEC-15, Section 4.1)

$n = 0.213 C_n \tau_o^{-0.4} = 0.213(0.238)(0.61)^{-0.4} = 0.062$

The discharge is calculated from Manning's equation (Refer to FDM 13-30-10, Equation 1):

$$Q = \frac{1.49}{n} A R^{2/3} S_0^{1/2} = 1.49/0.062(4.00)(0.485)^{2/3}(0.02)^{1/2} = 8.4\ ft^3/s$$

Step 4. Since this calculated flow value is more than 2 percent different from the design flow, repeat step 2 with a new, estimated flow depth.

Step 2 (2nd iteration). Estimate a new depth more than the initial estimate as the calculated Q < given Q

d = 1.21 ft, and calculate the new geometric channel properties:

$A = Bd + Zd^2 = 0.0(1.21) + 4(1.21)^2 = 5.86\ ft^2$

$P = B + 2d\ (Z^2 + 1)^{1/2} = 0.0 + 2(1.21)\ (4^2 + 1)^{1/2} = 9.98$ ft

R = A/P = (5.86)/(9.98) = 0.587 ft

Step 3 (2nd iteration). To estimate n, determine the applied shear stress on the grass lining and the discharge:

$\tau_o = \gamma R S_o = 62.4(0.587)(0.02) = 0.73$ lb / ft (Refer to FDM 13-30-10, Equation 2)

Determine Manning's n from FDM 13-30-15, Equation 12:

$C_n = 0.237(C_s)^{0.1}(h)^{0.528} = 0.237(9.0)^{0.1}(0.67)^{0.528} = 0.238$ (HEC-15, Section 4.1)

$n = 0.213 C_n \tau_o^{-0.4} = 0.213(0.238)(0.73)^{-0.4} = 0.057$

The discharge is calculated from Manning's equation:

$$Q = \frac{1.49}{n} A R^{2/3} S_0^{1/2} = 1.49/0.057(5.86)(0.587)^{2/3}(0.02)^{1/2} = 15.2 \text{ ft}^3/\text{s}$$

Step 4 (2nd iteration) Since this value is within 2 percent of the design flow, proceed to step 5.

Step 5. The maximum shear on the channel bottom is.

$$\tau_d = \gamma d S_o = 62.4(1.21)(0.02) = 1.51 \text{ lb/ft}^2$$

The permissible soil shear stress is given by Equation 4.6., HEC-15 Section 4.3.3.2

$$\tau_{p,soil} = (c_1 PI^2 + c_2 PI + c_3)(c_4 + c_5 e)^2 c_6 = (1.07(16)^2 + 14.3(16) + 47.7)(1.42 - 0.61(0.35))^2(0.00010) = 0.08 \text{ lb/ft}^2$$

Equation 2 gives the permissible shear stress on the vegetation. The value of C_f is found in Table 4.5, HEC-15 Section 4.3.1. The soil grain roughness, n_s, equals 0.016 unless the D_{75} of the soil is greater than 0.05 in.

$$\tau_p = \frac{\tau_{p,soil}}{(1 - C_f)}\left(\frac{n}{n_s}\right)^2 = (0.08/(1\text{-}0.9))(0.057/0.016)^2 = 10.2 \text{ lb/ft}^2$$

The safety factor for this channel is taken as 1.0. (Refer to FDM 13-30-10, General Design Procedures)

Step 6. The grass lining is acceptable since the maximum shear on the vegetation (1.51 lb/ft^2) is less than the permissible shear of 10.2 lb/ft^2.

Grass Lined Channel Design WisDOT Spreadsheet Worksheet
Download a zipped working copy of the spreadsheets at:

http://wisconsindot.gov/rdwy/fdm/files/WisDOT-Stormwater-Drainage-WQ-Channel-Spreadsheets.zip

1 **Lining Type: Vegetation**

2	**Project ID:**
3	**Location:**
4	**Designer/Checker:**
5	**Date:**

6

7	**STA**	**10+00**	**10+00**	**12+00**	**13+00**	**14+00**	**15+00**	**16+00**	**17+00**
8	**Left, Center or Right**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
9	***Channel/Ditch Geometry***								
10	Channel Slope, S_0 (ft/ft)	**0.02**	**0.02**						
11	Channel Bottom Width, B (ft)	**0**	**0**						
12	Channel Side Slope, z_1	**4**	**4**						
13	Channel Side Slope, z_2	**4**	**4**						
14	Flow Depth, d (ft) Solve iteratively	**1.00**	**1.21**						
15	Safety Factor, SF	**1.0**	**1.0**						
16	***Vegetation/Soil Parameters***								
17	Vegetation Retardance Class	**C**	**C**						
18	Vegetation Condition	**good**	**good**						
19	Vegetation Growth Form	**turf**	**turf**						
20	Soil Type	**cohesive**	**cohesive**						
21	D_{75} (in) (Set at 0.00 for cohesive soils)								
22	ASTM Soil Class	**SC**	**SC**						
23	Plasticity Index, PI	**16**	**16**						
24	***Results Summary***								
25	Design Q (ft^3/s)	**15.0**	**15.0**						
26	Calculated Q (ft^3/s)	8.4	15.2	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
27	Difference Between Design & Calc. Flow (%)	-44.0%	1.2%	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
28	**Stable (Yes or No)**	**YES**	**YES**	**#VALUE!**	**#VALUE!**	**#VALUE!**	**#VALUE!**	**#VALUE!**	**#VALUE!**
29	***Channel Parameters***								
30	Vegetation Height, h (ft)	0.67	0.67	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
31	Grass Roughness Coefficient, C_n	0.238	0.238	undefined	undefined	undefined	undefined	undefined	undefined
32	Cover Factor, C_f	0.90	0.90	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
33	Noncohesive Soil								
34	Soil Grain Roughness, n_s	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
35	Permissible Soil Shear Stress, τ_n (lb/ft^2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
36	Cohesive Soil								
37	Porosity, e	0.35	0.35	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
38	Soil Coefficient 1, c_1	1.0700	1.0700	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
39	Soil Coefficient 2, c_2	14.30	14.30	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
40	Soil Coefficient 3, c_3	47.700	47.700	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
41	Soil Coefficient 4, c_4	1.42	1.42	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
42	Soil Coefficient 5, c_5	-0.61	-0.61	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
43	Soil Coefficient 6, c_6	0.00010	0.00010	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
44	Permissible Soil Shear Stress, τ_n (lb/ft^2)	0.080	0.080	N/A	N/A	N/A	N/A	N/A	N/A
45	Total Permissible Shear Stress, τ_n (lb/ft^2)	0.080	0.080	0.000	0.000	0.000	0.000	0.000	0.000
46	Cross Sectional Area, A (ft^2)	4.000	5.856	0.000	0.000	0.000	0.000	0.000	0.000
47	Wetted Perimeter, P (ft)	8.25	9.98	0.00	0.00	0.00	0.00	0.00	0.00
48	Hydraulic Radius, R (ft)	0.485	0.587	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
49	Top Width, T (ft)	8.00	9.68	0.00	0.00	0.00	0.00	0.00	0.00
50	Hydraulic Depth, D (ft)	0.500	0.605	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
51	Froude Number (Q design)	0.523	0.587	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
52	Channel Shear Stress, τ_n (lb/ft^2)	0.61	0.73	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
53	Actual Sheer Stress, τ_d (lb/ft^2)	1.25	1.51	0.00	0.00	0.00	0.00	0.00	0.00
54	Mannings n	0.062	0.057	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
55	Average Velocity, V (ft/s)	3.75	2.56	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
56	Calculated Flow, Q (ft^3/s)	8.4	15.2	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
57	Difference Between Design & Calc. Flow (%)	-44.0%	1.2%	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
58	Effective Shear on Soil Surface, τ_e (lb/ft^2)	0.008	0.012	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
59	Total Permissible Shear on Veg., $\tau_{n\,veg}$ (lb/ft^2)	12.03	10.17	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
60	Stable (Y or N)	YES	YES	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

GRASS LINED CHANNEL DESIGN EXAMPLE (USING WISDOT SPREADSHEET)

To use this spreadsheet, enter data into all the grey cells. The spreadsheet is designed so that you can select the cells in column C from rows 5 to 52 and drag them across to create additional columns for additional swale segments.

Enter the following information into the spreadsheet, as shown in the example to the right. Note that many of the variables are selected using a drop-down list box. In Figures 1 to 3, the first data column represents values from the first iteration of the above example, and the second column displays values from the second iteration of the above example.

Lines 2 – 5: Enter the project information as described.

Lines 7 – 8: For each channel segment, enter the highway station and whether the channel is on the left, center or right (L, C or R) of the highway.

Line 10: Enter the channel bottom slope, S_o, (ft/ft).

Line 11: Enter the channel bottom width, B, (ft).

1 **Lining Type: Vegetation**

2	**Project ID:**
3	**Location:**
4	**Designer/Checker:**
5	**Date:**
6	

7	**STA**	**10+00**	**10+00**
8	**Left, Center or Right**	**R**	**R**
9	***Channel/Ditch Geometry***		
10	Channel Slope, S_o (ft/ft)	**0.02**	**0.02**
11	Channel Bottom Width, B (ft)	**0**	**0**
12	Channel Side Slope, z_1	**4**	**4**
13	Channel Side Slope, z_2	**4**	**4**
14	Flow Depth, d (ft) Solve iteratively	**1.00**	**1.21**
15	Safety Factor, SF	**1.0**	**1.0**
16	***Vegetation/Soil Parameters***		
17	Vegetation Retardance Class	**C**	**C**
18	Vegetation Condition	**good**	**good**
19	Vegetation Growth Form	**turf**	**turf**
20	Soil Type	**cohesive**	**cohesive**
21	D_{75} (in) (Set at 0.00 for cohesive soils)		
22	ASTM Soil Class	**SC**	**SC**
23	Plasticity Index, PI	**16**	**16**

Figure 15.1 Grass Lined Channel Design Spreadsheet Data Entry Section

Lines 12-13: Enter the side slopes of the channel (z_1,z_2) (z Horizontal: 1 Vertical)

Line 14: Enter the initial estimate of the water depth, d, in the swale (ft).

Line 15: SF, the selected safety factor.

Line 17: Vegetation Retardance Class (A, B, C, D, or E) selected from a drop-down menu.

Line 18: Vegetation condition (good, fair or poor), selected from a drop-down menu

Line 19: Vegetation growth form (bunched, mixed or turf), selected from a drop-down menu. Select “bunched” for seed mixes 70, 70A, 75 and 80.

Line 20: Soil Type (cohesive or non-cohesive) of the soil you are constructing the swale on, selected from a drop-down menu.

Line 21: If non-cohesive, enter the D_{75} of the soil. Typical values are listed on Table 2. Set this value to zero for cohesive soils.

Line 22: If cohesive, enter ASTM Soil Class (CH, CL, GC, GM, MH, ML, SC, SM) of the soil, selected from a drop-down menu.

Line 23: If cohesive, enter the PI (Plasticity Index) of the soil. This value can be obtained from the soils engineer or from the NRCS website: http://websoilsurvey.nrcs.usda.gov/app/ and begin by pressing the ‘Start WSS’ button. To determine the PI:

1. Draw an outline around the geographic area of interest (AOI) of your project.
2. Select the ‘Soil Data Explorer’ tab.
3. Select the ‘Soil Properties and Qualities’ tab.

4. Select 'Plasticity Index' from the 'Soil Physical Properties' menu.
5. Select the 'Layer Option' you want and enter a depth range, if appropriate.
6. Press the 'View Rating' button to view the plasticity index of your area of interest. Use the value in the Ratings (percent) column of the Plasticity Index Table for the PI value of the soil types in your AOI.

Grass Lined Channel Design Results Summary

24	***Results Summary***		
25	Design Q (ft^3/s)	**15.0**	**15.0**
26	Calculated Q (ft^3/s)	8.4	15.2
27	Difference Between Design & Calc. Flow (%)	-44.0%	1.2%
28	**Stable (Yes or No)**	**YES**	**YES**

Figure 15.2 Grass Lined Channel Design Spreadsheet Results Summary Section

Line 25: Enter the design flow for the channel section, in ft^3/s.

Line 26: The calculated flow for the channel, based upon the depth of flow you entered, the channel geometry, and the grass swale parameters.

Line 27: The percent difference between the design flow and the calculated flow.

Line 28: Channel bottom lining stability status (Yes or No).

Analysis Process:

Once you have entered all relevant information, you must change the channel depth, d, in Line 13 until the difference in the Design Q and the Calculated Q is less than 2%. The spreadsheet will indicate, in Line 27, whether the grass lined channel is stable or unstable.

If the channel is unstable, you have the following options:

1. Flatten the longitudinal slope by either modifying the slope grade or putting in permanent ditch checks that are not in the clear zone. If you use properly spaced permanent ditch checks, assume a longitudinal slope of 1%. Ditch checks should be spaced such that the base of the upstream check is at the same elevation as the top of the downstream check
2. Flatten the side slopes and/or widen the ditch bottom to decrease the flow depth
3. Select a different liner, such as a TRM (Turf Reinforcement Mat) or riprap

Grass Lined Channel Spreadsheet Intermediate Calculations

The intermediate calculations are values determined by the spreadsheet, based upon the procedures described in HEC-15. The user does not enter any of these values into the spreadsheet.

29	***Channel Parameters***		
30	Vegetation Height, h (ft)	0.67	0.67
31	Grass Roughness Coefficient, C_n	0.238	0.238
32	Cover Factor, C_f	0.90	0.90
33	Noncohesive Soil		
34	Soil Grain Roughness, n_s	0.016	0.016
35	Permissible Soil Shear Stress, τ_n (lb/ft^2)	N/A	N/A
36	Cohesive Soil		
37	Porosity, e	0.35	0.35
38	Soil Coefficient 1, c_1	1.0700	1.0700
39	Soil Coefficient 2, c_2	14.30	14.30
40	Soil Coefficient 3, c_3	47.700	47.700
41	Soil Coefficient 4, c_4	1.42	1.42
42	Soil Coefficient 5, c_5	-0.61	-0.61
43	Soil Coefficient 6, c_6	0.00010	0.00010
44	Permissible Soil Shear Stress, τ_n (lb/ft^2)	0.080	0.080
45	Total Permissible Shear Stress, τ_n (lb/ft^2)	0.080	0.080
46	Cross Sectional Area, A (ft^2)	4.000	5.856
47	Wetted Perimeter, P (ft)	8.25	9.98
48	Hydraulic Radius, R (ft)	0.485	0.587
49	Top Width, T (ft)	8.00	9.68
50	Hydraulic Depth, D (ft)	0.500	0.605
51	Froude Number (Q design)	0.523	0.587
52	Channel Shear Stress, τ_o (lb/ft^2)	0.61	0.73
53	Actual Sheer Stress, τ_d (lb/ft^2)	1.25	1.51
54	Mannings n	0.062	0.057
55	Average Velocity, V (ft/s)	3.75	2.56
56	Calculated Flow, Q (ft^3/s)	8.4	15.2
57	Difference Between Design & Calc. Flow (%)	-44.0%	1.2%
58	Effective Shear on Soil Surface, τ_e (lb/ft^2)	0.008	0.012
59	Total Permissible Shear on Veg., $\tau_{n\ veg}$ (lb/ft^2)	12.03	10.17
60	Stable (Y or N)	YES	YES

Figure 15.3 Channel Parameters Section Spreadsheet Data

Channel Parameters:

Line 30: The vegetation height, from Table 1 in this procedure and from HEC-15 Table 4-1.

Line 31: The grass roughness coefficient, from HEC-15, Equation 4.1.

Line 32: The cover factor, from HEC-15, Table 4-5.

Lines 34 - 35: Calculations, described in HEC-15, to determine the permissible soil shear stress for noncohesive (or sandy) soils.

Line 37 - 45: Calculations and coefficients, described in HEC-15, to determine the permissible soil shear stress for cohesive soils.

Line 46: The cross section area, based upon the depth of flow (line 14) and channel geometry.

Line 47: The wetted perimeter, based upon the depth of flow (line 14) and channel geometry.

Lines 48: The hydraulic radius, based upon the depth of flow (line 14) and channel geometry.

Line 48: The top width, based upon the depth of flow (line 14) and channel geometry.

Line 50: The hydraulic depth, which is the area (line 45) divided by the top width (line 48).

Line 51: The Froude number, which is a function of the calculated flow, the cross sectional area, the gravitational constant, g, and the hydraulic depth.

Line 52: The channel shear stress, which is a function of the hydraulic radius (line 47), the channel slope (line 9), and the density of water. This value is used to calculate Manning's n.

Line 53: The actual shear stress, which is a function of the flow depth (line 13), the channel slope (line 9), and the density of water. This value is used to determine the effective shear on the soil, and thus the stability of the channel.

Line 54: The Manning's n value selected by the spreadsheet, which is determined in the Manning's n

spreadsheet section below.

Line 55: The average velocity, which is found by dividing the calculated flow (line 25) by the cross section area (line 45).

Line 56: The calculated flow, which is calculated using Manning's equation.

Line 57: The percent difference in flow between the calculated flow and the design flow.

Line 58: The effective shear stress of the grass lining, which is due to the shear force dissipation due to the grass stems and the grass plant stabilization (both root and stem) against turbulent fluctuations.

Line 59: Total permissible shear of the vegetative lining, which includes the combined effects of the soil permissible shear stress and the effective shear stress transferred through the vegetative lining.

Line 60: The channel is stable if the permissible shear stress (line 58) is greater than the effective shear stress (line 52) times the safety factor (line 14).