APPENDIX H

DESIGN EXAMPLES

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H.I Introduction

In this section, 17 design examples are included to illustrate the successive stages involved in the design of erosion measures required in a grading project.

The different phases of erosion control calculations and design, and the corresponding examples, are shown in the following table.

Description		Example
Erosion Potential	Single Slope	H.1, H.6
	Irregular (bench) Slope	H.4, H.5
	Low Embankment Slope	H.7
	Variation with Soil Types	H.3a, H.3b
	For Varying Site Hazards	H.2
Channel Protection	Vegetative Lining	H.8
	RECP Mat (soil covering) Lining	H.9
	Gravel Lining	H.10
	Riprap Lining	H.11
	Concrete Lining	H.12
	Gabion Mat Lining	H.13
Flow Depth Estimation		H.14
Sediment Barriers – Storage Capacity		H.15
Sediment Basin/Trap		H.16

Example H.1 (Erosion – Single Slope)

A highway construction site just north of the city of Edmonton requires the excavation of a large uniform cut-slope approximately 30m in length at a 3H:1V slope (roughly 33%). Excavation and grading of the slope is to occur through the spring and summer (May through August) and the site will be highly disturbed during the course of the construction period. Top soil placement and seeding is scheduled to take place at the end of August.

The exposed soils are expected to be normally consolidated and consist of silty clay. Supporting field investigation information for the soil indicates the following:

Agriculture Soil Data	**Geotechnical Soil Data**
Classification: CL	Classification CL-ML
50% Silt and Very Fine Sand	Plasticity Index (PI) = 15
10% Sand >0.1 mm	Plastic Limit (PL) = 27
0% Organic Matter Content	Moisture Content = 26%

Using the RUSLE, determine the Site Erosion Potential for this particular construction site.

1. Determine the appropriate Rainfall Factor (R_t) for the Construction Area.

   From the Isoerodent Map (Figure B-1) the R-factor for the Edmonton area is 350 (MJ mm ha^{-1} year^{-1}) and the corresponding winter adjustment value (Figure B-3) R_s is 20 (MJ mm ha^{-1} year^{-1}). The total rainfall factor R_t is therefore 370 (MJ mm ha^{-1} year^{-1}).

2. Determine the Monthly Distribution of the Rainfall Factor (R_t).

   The monthly distributions are summed for the period of anticipated construction that the soil is expected to be exposed (e.g., without top soil/vegetation). In this example, top soiling and seeding is scheduled to occur at the end of August.

   The summed monthly distributions are expressed as a percentage of the total annual value.

   From the supporting information (Table B-1 and Figure B-4) shown in Appendix B. The monthly distribution (Figure B-4) of the Rainfall factor for the Edmonton area over the construction months is as follows: May (10%), June (20%), July (25%) and August (15%). Therefore, R_t for this particular site over the period of construction noted is equal to 240 (MJ mm ha^{-1} year^{-1}), which is about 70% of the total annual value.

3. Determine the Slope Factor (LS).

   The slope factor table, which supports the equation for a uniform slope is shown on Table B-3.

   For an average slope length of 30 m with a slope gradient of 33% a corresponding slope factor of approximately 5.4 is interpolated.

   Applying the suggested Topographic Adjustment factor ($Ø_{LS}$) of 0.8 (see Section 6.2.3.2) results in an adjusted LS of 4.3.

4. Determine the Soil Erodibility Factor (K) for the Soil to be exposed during Construction.

   From Figures B-6 and Figure B-7, Clay Loam has a corresponding Structure Code of 4 and a Permeability Code of 4.

   Using the Soil Erodibility Nomograph in Figure B-5 for the given soil structure, permeability and composition, the exposed soil is estimated to have an Erodibility Factor (K) of 0.047.

   Applying the suggested Soil Erodibility Adjustment factor ($Ø_K$) of 0.8 (see Section 6.2.2.2) results in an adjusted K of 0.038.

5. Determine Management (C) and Support Practice (P) Factors.

   This slope is expected to produce a highly disturbed surface that is relatively compacted and smooth from the excavation and grading process. Furthermore no treatments are being applied to the slope, therefore the C Factor (Table B-6) and P Factor (Table B-7), for this site follow that for a bare soil (packed and smooth) and are both equal to 1.0.

   It should be noted that some immediate reduction (from 1.0 to 0.9) can be made to the Support Practice (P) Factor if the slope is roughened during the excavation grading process. Roughening of the slopes is considered a Minimum Measure for all slopes.

6. Calculate the Soil Erosion Potential (Soil Loss) for this Construction Site.

   A summary of the RUSLE parameters is as follows:

   Rt = 240 (MJ mm ha^{-1} $year^{-1}$) (adjusted for construction season 0.70 of annual)

   K = 0.038 (adjusted by $Ø_K$ = 0.8) (MJ mm ha^{-1} $hour^{-1}$)

   LS = 4.3 (adjusted by $Ø_{LS}$ = 0.8)

   C = 1.0

   P = 0.9 (with slopes roughened)

   Using RUSLE: **Estimated Soil Loss (A) = R x K x LS x C x P**

   Soil Loss (A) = 35.3 (tonnes ha-1 year -1)

   This value represents the estimated soil loss from this site over the period of construction prior to placement of top soil and seeding.

Example H.2 (Erosion Potential and Site Hazard)

1. Determine the Site Erosion Hazard Classification for the soil loss evaluated in Example H.1 where Soil Loss (A) = 29.7 tonne ha^{-1} $year^{-1}$.

Based on the estimated site erosion potential for the period of construction noted, and the general hazard classes shown in Table 6.1, a HIGH site hazard class is indicated for this particular slope.

RUSLE Erosion Hazard Classification		Site Hazard Evaluation	
Soil Erosion Potential (A) (tonnes/ha/yr)	**Site Hazard Class (RUSLE)**	**Soil Loss (tonne/ha/yr)**	**Hazard Class**
<6	Very Low		
6-11	Low		
11-22	Moderate		
22-33	High		
>33	Very High	35.3	Very High

Example H.3a (Variations of Erosion Potential for Soil Types using RUSLE (Section 6.2)

Various Soil Types:

Using the average K values (from Table B-2, Appendix B) for various soil textures and multiply by $Ø_R$, similar evaluation are assessed for varying soils for the similar site condition in Example H.1. The following table provides a summary of various soils types for the same construction site to show the sensitivity of site erosion potential classification to various types of soil.

Table Comparing Various Soils and Erosion Potential (Edmonton Area)

Soil Type	Average Erodibility Factor (K) x $Ø_K$	Soil Loss Potential (A)	Site Erosion Potential
Very Fine Sand	0.057 x 1.0 = 0.057	52.9	Very High
Silt Loam	0.050 x 0.8 = 0.040	37.1	Very High
Clay Loam	0.040 x 0.8 = 0.032	29.7	High
Clay	0.03 x 0.8 = 0.024	22.3	Moderate to High
Sandy Loam	0.017 x 0.8 = 0.014	13.0	Moderate
Heavy Clay	0.02 x 0.8 = 0.016	14.9	Moderate
Coarse Sandy Loam	0.009 x 0.8 = 0.007	6.5	Low to Very Low
Sand	0.001 x 1.0 = 0.001	0.9	Very Low

Note: Soil Loss Potential (A) in tonnes/ha/year

Note that for the same soil type (e.g., Clay Loam to Sandy Clay Loam) two different erodibility factors and subsequently site erosion potentials are calculated. This demonstrates the sensitivity of the soil class and the importance of determining the proper soil classification based on all available information such as geotechnical assessments and lab testing. It is noted that for sand material, no modifications to Erodibility is applied (i.e., $Ø_R$=1). The use of typical values for determining the soil erodibility factor (K) is only recommended when specific soil information is unavailable or cannot be obtained.

Example H.3b (Variation of Erosion Potential for Sample Alberta Soils – Preliminary Estimate using USCS Chart (Figure 4.3) and Common Soil Testing Data for Highway Construction)

In this example, typical highway soil testing (grading design only) are presented to show that a preliminary measurement of soil erodibility potential can be assessed from plasticity and gradation data. Only a portion of Alberta areas is presented for illustration.

Soil type variations across Alberta are a function of a geological deposition process and geomorphology at the locations of highway construction. Soil investigation surveys for grading construction generally provide the following general and additional soil information for highway designs:

A) General Information	1.	Plasticity Index (PI)
	2.	Soil Classification (USCS)
	3.	Field Moisture (M.C.) (%)
	4.	Estimated Optimum Moisture (OMC) (%)
	5.	Estimated Proctor Density (kg/m³)
B) Additional Information (if required)	1.	Gradation – coarse granular soil
	2.	Hydrometer gradation – fine grained and/or cohesive soil

The preliminary assessment of soil erodibility (by USCS chart approach) is presented in Appendix A for soil data obtained for some Alberta sites.

Example H.4 (Erosion Potential of Irregular (benched) Slope)

The effect of slope shape with multiple slope segments in reducing erosion potential is demonstrated in the following example:

- A long slope with narrow benches at the top and in the middle of the excavation is to be constructed at the same site as defined in the above example (i.e., similar soil and location). The total length of the slope is roughly 70 m and is divided into 4 segments with the following geometry.

Slope Description Summary

Slope Segment *	Slope Length	Slope Gradient
1 – Top Bench *	5.5 m	2%
2 – Mid-Slope	30 m	33% (3:1)
3 – Mid-Bench	3 m	2%
4 – Base Slope	30 m	33% (3:1)

Note * The effect and inclusion of the top bench (Slope Segment #1) as one slope segment can provide an under-estimate of slope erosion potential; therefore the top slope segment is ignored and only 3 segments of slope are considered (#2, 3 and 4).

For each of the three effective slope segments, the slope factor (LS), slope length exponent (m) and appropriate soil loss factor (SLF) needs to be determined. These values can be easily taken from the supporting tables provided in Appendix B. Once a value for each segment has been derived, the actual slope factor (LS) for the separate segments can be determined as shown in the following summary:

Summary of Slope Factors for Slope with 3 Segments of Benched Slope

Slope Segment #	Slope Factor (LS) Table B-3	Slope Length Exponent (m) Table B-4	Soil Loss Factor (SLF) Table B-5	Segment LS (LS x SLF)
1 – Top Bench (N/A)	0.2	0.24	0.71	0.14 (N/A)
2 – Mid-Slope	4.3	0.66	0.87	3.74
3 – Mid-Bench	0.2	0.24	1.11	0.22
4 – Base Slope	4.3	0.66	1.50	6.45
				∑ Segments (LS) = 10.41
				Benched Slope Average LS = 10.41/3 = 3.5

Once the Slope Factor (LS) has been determined for each of the slope segments, the total LS for the slope is determined by summing the LS Segments (10.41) and dividing it by the number of effective slope segments (3). For this particular benched slope, the averaged LS is about 3.5. In comparison with a base slope of half height (Slope Segment #4, base slope with Segment LS = 6.45), the erosion potential (LS = 3.5) of a benched slope of twice the height is approximately 54% (i.e., LS ratio @ 3.5/6.45). In comparison with the mid-slope (Segment #2) with half height at LS = 3.74, the ratio of erosion potential of the benched slope of twice the height is approximately 93% (i.e., LS ratio @ 3.5/3.74).

This example shows the benefit of irregular slope configurations with intermediate benching can effectively reduce the erosion potential close to the equivalent of a single slope at the top half of the bench slope. It also shows that the lower portion of a benched high slope have higher erosion potential (LS = 6.45) compared with the top portion of the benched high slope (LS = 3.74).

Example H.5 (Erosion Potential of Benched Slope)

It is proposed to reduce the soil erosion on a 15 m high simple 3:1 slope by providing a 3 m wide berm at midslope (Fig. H.5). Estimate the percentage reduction in sediment yield for:

- single slope vs. benched slope
- single slope (15 m height) vs. single slope (7.5 m height)

Is benching of slope more advantageous to reducing slope height?

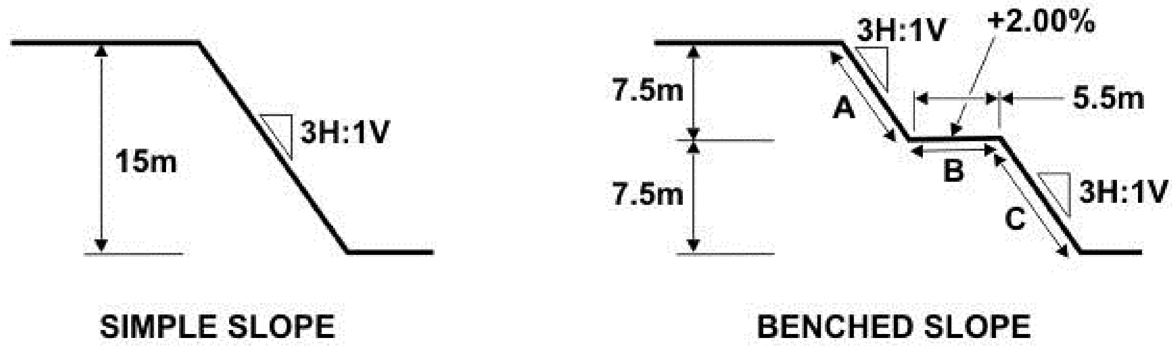


Figure (Example H.5): Cross-section with and without a bench

Step 1: Topographic Soil Loss Factor (LS) from un-benched simple slope

Length along the slope face, L = 15 x 3.2 = 48 m

For L = 48 m and slope = 33.33%, LS = 7 (from Table B-3, Appendix B)

Step 2: Topographic Soil Loss Factor (LS) from benched slope

Slope Segment	Vertical Height (m)	Inclined Length Along Slope (m)	Slope (%)	LS Factor (Table B-3 App. A)	m Factor (Table B-4 App. A) Moderate	SLF (Table B-5 App. A)	LS x SLF
A	7.5	23.7	33.3	4.7	0.66	0.5	2.35
B	0.0	3.0	2	0.18	0.24	1.02	0.18
C	7.5	23.7	33.3	4.7	0.66	1.46	6.86
							∑ = 9.39

$$Bench\ Slope = \frac{9.39}{3} = 3.1$$

Step 3:

Compare two cases:

a) Single slope vs. benched slope

Percentage soil loss from benched slope = LS bench slope/LS single slope = 3.1/7 = 53%

LS percentage reduction = (100% - 53%) = 47% reduction of soil loss (slope design component)

b) Single slope (15 m high) vs. single slope (7.5 m high)

Percentage soil loss from low height single slope = LS lower slope/LS high single slope = 4.7/7 = 67%

LS percentage reduction = (100% - 67%) = 33% of soil loss (slope design component) reduction.

Step 4:

In comparison with a single long slope (3H:1V), the benching of slope (full 15 m height) yields a 47% reduction in sediment yield; whereas the reduction of slope height (to 1/2 height at 7.5 m) only yields a 33% reduction in sediment yield. The benching of slope is more effective in reducing the percent erosion and sediment yield in comparison with reducing slope height.

Example H.6 (Erosion Potential of a Low Cutslope – Seasonal)

A simple 3:1 backslope in Grande Prairie is to be constructed in a medium plastic (CI) clay having the grain size distribution given. If the configuration of the slope is as shown in Figure (Example H.6), estimate the mean annual soil loss. What would the soil loss during the construction season from July to October?

Grain size distribution:

Fraction	Percentage
Sand (2 - 0.1 mm)	7
Very fine sand (0.1 - 0.05 mm)	10
Silt (0.05 - 0.002 mm)	49
Clay (< 0.002 mm)	34

Organic Content = 0%
Sand Structure = Blocky Platy Massive
Permeability = Slow

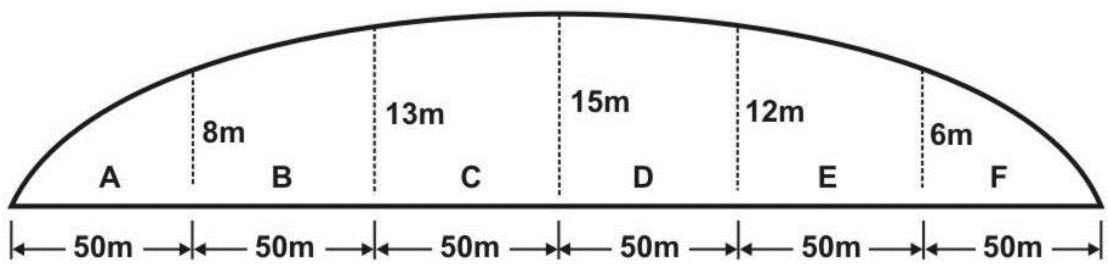


Figure (Example H.6): Elevation of Slope

Solution:

Soil loss	= R.K.LS.C.P (from Equation 6.1)
R	= 385 (from Figures B-1, Appendix B)
K	= 0.032 (clay from Table B-2, Appendix B)
$Ø_K$	= 0.8 (highway modification factor suggested for K)
$K_{highway}$	= 0.8 x 0.032 = 0.026
CP	= 1.0 (from Tables B-6a and B-7)
LS	= variable with each slope segment = $LS_{average}$ = 4.8
$Ø_{LS}$	= 0.8 (highway modification factor suggested for LS)
$LS_{highway}$	= 0.8 x 4.8 = 3.8
Area	= Length x average slope length = 50 m x (4+10.5x14+13.5+9+3)m
	= 50 m x 54 m = 2700 m² = 0.27 Ha

Slope Segment	Mean length along the slope face (m)	Slope (%)	LS factor (Fig. 6.4)
A	12.6	33.3	2.6
B	33.2	33.3	6
C	44.3	33.3	6.5
D	42.7	33.3	6.5
E	28.5	33.3	5.0
F	9.5	33.3	2.6
Average:	28.5	33.3	4.8

Note: 1 Ha = 100 m x 100 m = 10,000 m²

Mean annual soil loss = R.K.CP.LS.Area ($K = K_{highway}$; $LS = LS_{highway}$)

= 385 x 0.026 x 1.0 x 3.8 x 0.27 Ha

= 10.3 tonnes/yr

Referring to Figure B-3, Appendix B (monthly rainfall distribution) for Grande Prairie.

Total percentage of soil loss from July to October = 14 + 18 + 10 + 5 = 47%.

Hence, expected soil loss from July to October = 0.47 x 10.5 = 4.8 tonnes.

Example H.7 (Erosion Potential of a Low Fill Embankment)

A soil classified as a low plastic silt (ML) according to the Unified Soil Classification System is used to construct a secondary highway embankment construction (Example H.7). Estimate the mean annual soil loss from typical low fill (1m @ 4H:1V) embankment in the Edmonton area and the grain size distribution is as given below:

Fraction	Percentage
Sand (2.0 – 0.10 mm)	22%
Very fine sand (0.10 – 0.05 mm)	5%
Silt (0.05 – 0.002 mm)	54%
Clay (<0.002 mm)	19%
Organic	0%

- To Find Soil Erodibility k = 0.064

  Use of Erodibility Nomograph (Figure B-5, Appendix B)

  % Sand + % Silt = 59%

  % Sand = 22%

  % Organic = 0%

  Soil Structure = blocky, platy, massive (4)

  Permeability = Slow to Moderate (4)

- To Find Soil Erodibility Rating (use Figure 4.2, Section 4.4.3)

  USCS Soil: ML – Erodibility Rating = High

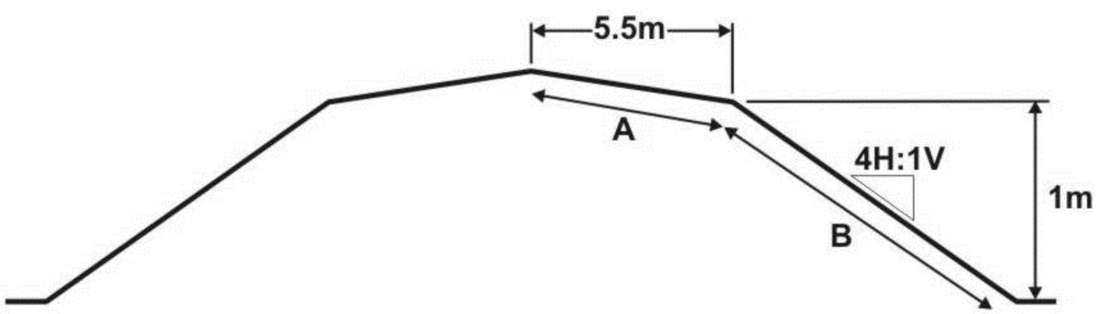


Figure (Example H.7): Secondary Highway Embankment Cross-Section

Solution:

Soil loss/hectare (A) = R K LS CP (from Equation 6.1)

R = 350 (from Figures B-1 and B-2, Appendix B)

K = 0.064 for the given soil information (Figure B-4, Appendix B)

CP = 1.0 (from Tables B-6a and B-7, Appendix B)

Equivalent LS value calculations (for half of the road cross-section):

Slope Segment	Vertical Height (m)	Inclined length Along Slope Face (m)	Slope (%)	LS factor (Table B-3) (Appendix B)	Remarks
A	0.0	5.5	2	0.12 (N/A)	Treated as simple slope, neglect the top segment.
B	1.0	4.12	25	1.77	This LS value is for a simple slope.

Hence, Soil Loss = R.K.LS.CP

= 370 x 0.064 x 1.77 x 1.0 = 41.9 tonnes/ha/yr (agriculture soil loss)

Therefore, Soil Erosion Potential (41.9 tonne/ha/yr) is very high (Table 6.1) in agriculture practice.

Hence, for highway construction, apply suggested highway modification factor ($Ø_K$ and $Ø_{LS}$) for K and LS:

$Ø_k$ = 0.8 to K

$Ø_{LS}$ = 0.8 to LS

Soil Loss (highway) = 41.9 t/ha/yr x 0.8 x 0.8 = 26.9 tonne/ha/yr ↔ High Erosion Hazard

Therefore, Soil Erosion Potential (26.9 tonne/ha/yr) is high (Table 6.1) in the highway construction practice. Erosion control measures such as scheduling can be adopted to effect completion of short sections of roadway in a few months followed by speedy topsoiling and seeding. This will reduce the soil erodibility for the whole year (370 tonne/ha/year) to part of a year (240 tonne/ha/year) as shown in Example H.1. Thus, with speedy construction scheduling, it will reduce the Soil Erosion Potential to Moderate for 17.4 tonne/ha/half year period (i.e., 240/370 of 26.9 tonne/year).

Example H.8 (Channel Protection – Vegetation Lining)

A roadside ditch having the geometric properties listed below is required to discharge 1 in 10 year storm estimated at 0.1 m^3/s (Figure Example H.8). Determine whether unmowed, full grown Kentucky Bluegrass having a height of 250 mm will be adequate as a ditch lining.

Bed width = 3.5 m Sideslope = 4:1

Backslope = 3.1 Ditch grade = 5% = 0.05

Solution:

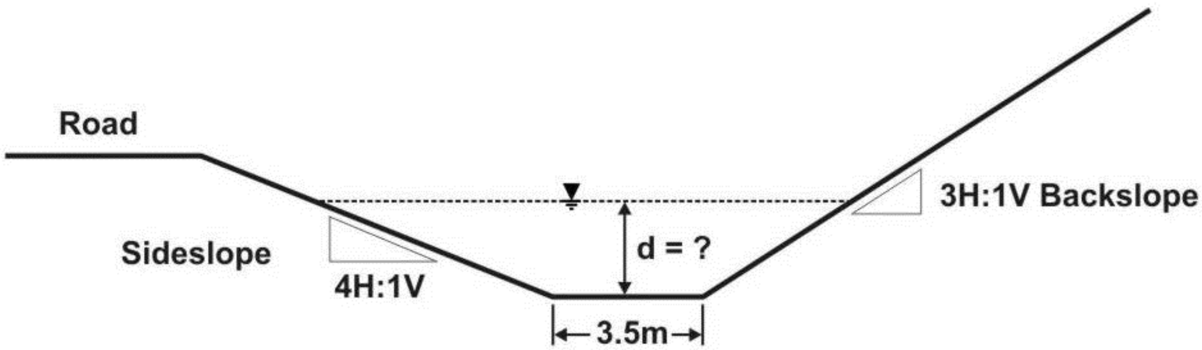


Figure (Example H.8): Typical Cross-Section

Step 1: Find the classification for the grass.

From Table F.3(a), vegetative retardance class could be either upper end of Retardance C or lower end of B; assume Retardance C.

Step 2: Estimate the depth of flow.

Trial 1:

Assume flow depth, d = 0.075 m

Top width of flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 (3.5 + 4.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.046 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

From Figure F.4, for R = 0.228 ft, slope = 0.05, Manning's n = 0.28 (for Vegetation C)

Discharge, Q = (1/n) A $R^{2/3}$ $s^{1/2}$ (from Equation F.3)

= (1/0.28) (0.282) ($0.0697^{2/3}$) ($0.05^{1/2}$)

= 0.038 m^3/s < 0.100 m^3/s, required

Hence, increase assumed flow depth.

Trial 2:

Revised flow depth, d = 0.10 m

Top width flow area = 3.5 + 4 x 0.1 + 3 x 0.1 = 4.2 m

Cross-sectional area, A = 0.5 x 0.1 x (3.5 + 4.2) = 0.385 m^2

Wetted perimeter, P = 3.5 +0.1 (3.162 + 4.123) = 4.228 m

Hydraulic radius, R = A/P = 0.385/4.228 = 0.091 m = 0.298 ft

From Figure F.4, for Vegetation Class C, R = 0.298 ft, slope = 0.05, Manning's n = 0.18

Discharge, Q = (1/n) A $R^{2/3}$ $s^{1/2}$ (from Equation F.3)

= (1/0.18) (0.385) ($0.091^{2/3}$) ($0.05^{1/2}$)

= 0.096 m^3/s < 0.100 m^3/s, required

The estimated discharge and the required discharge are very close and a flow depth of 0.1 m is o.k.

Step 3: Check the shear resistance of the grass lining.

Tractive shear stress of flow, $\tau_p = \rho$ d s (from Equation F.5)

= 9.81 x 0.100 x 0.05

= 0.049 kPa

(since, s = slope of channel = 0.05

d = depth of flow = 0.100m

δ_w = unit weight of water = 9.81 KN/m^3)

Shear resistance of Vegetation Class C = 0.048 kPa (from Table F.3(c))

Hence, the Kentucky Bluegrass lining is considered adequate.

Example H.9 (Channel Protection – Mat (soil covering) Lining)

Design a temporary ditch lining for the channel conditions in Example H.8. Assume the exposed natural ground in the ditch is incapable of resisting soil erosion in the ditch (Figure Example H.9).

Channel geometry: Sideslope = 4:1 Backslope = 3:1

Bed width = 3.5 m Ditch grade = 5% = 0.05

Discharge = 0.100 m^3/s

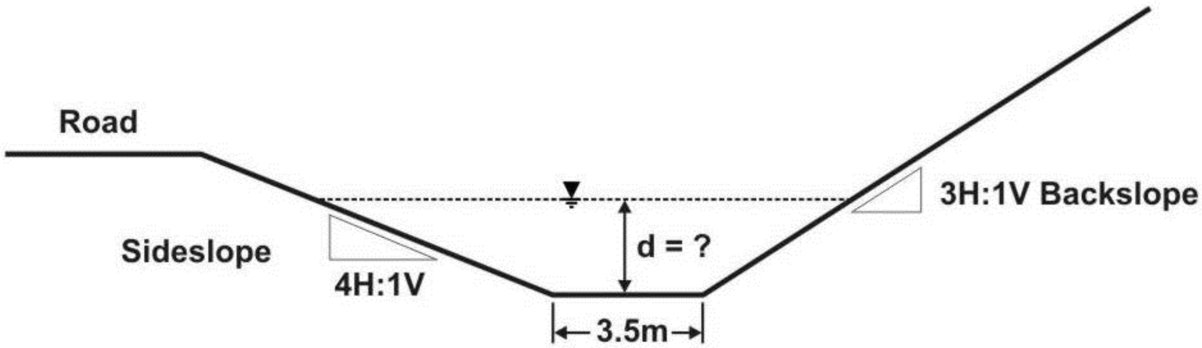


Figure (Example H.9): Typical Cross-Section

Solution:

Assuming use of a straw or wood excelsior mat

Manning's n = 0.065 (from Table F.2)

Step 1: Estimate the depth of flow.

Trial 1:

Assume depth of flow = 0.075 m

Top width of the flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 x (3.5 + 4.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.045 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

Discharge, Q = $(1/n)\ A\ R^{2/3}\ s^{1/2}$ (Equation F.3)

= $(1/0.065)\ (0.282)\ (0.0697^{2/3})\ (0.05^{1/2})$

= 0.161 m^3/s > 0.100 m^3/s

Hence, revise the depth of flow to a lower value, say, d = 0.060 m

Trial 2:

Top width of the flow = 3.5 + 4 x 0.060 + 3 x 0.060 = 3.92 m

Cross-sectional area, A = 0.5 x 0.060 (3.5 + 3.92) = 0.222 m^2

Wetted perimeter, P = 3.5 + 0.060 (3.162 + 4.123) = 3.93 m

Hydraulic radius, R = A/P = 0.222/3.93 = 0.0564 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$

$= (1/0.066)\ (0.222)\ (0.0564^{2/3})\ (0.05^{1/2})$

$= 0.112\ m^3/s > 0.100\ m^3/s$

Hence, the depth of flow is close to 0.060 m, may be like 0.058 m.

Step 2: Check the shear resistance of the erosion control mat.

Tractive shear stress of flow, $\tau_p = \delta\ d\ s$ (Equation F.5)

= 9.81 x 0.060 x 0.05

= 0.029 kPa = 29 Pa

Permissible shear stress of manufactured mat (such as Excelsior mat) = 74 Pa (from Table F.3(c)).

Hence, curled wood mat (Excelsior mat) is more than adequate as a temporary ditch lining.

Example H.10 (Channel Protection – Gravel Lining)

A roadside ditch, similar in cross-section in Example H.9, is required to carry a 1 in 10 year storm discharge of 0.15 m^3/s (Figure H.7). Determine the mean diameter of granular material that is required to permanently control soil erosion.

Ditch cross-section information:

Bed width = 3.5 m Sideslope = 4:1

Backslope = 3:1 Grade = 5%

Solution:

Assume using rock riprap, D_{50} = 150 mm

Corresponding value of Manning's n = 0.104 (from Table F.2)

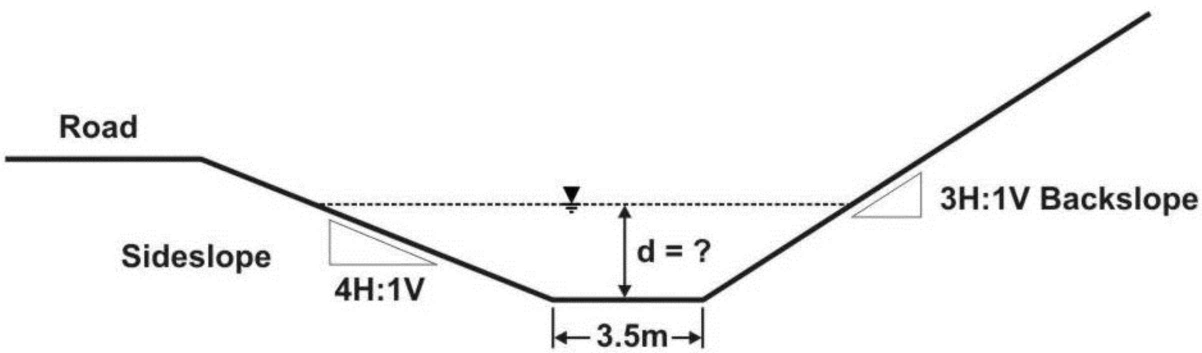


Figure (Example H.10): Typical Cross-Section

Step 1: Estimate the depth of flow.

Trial 1:

Flow depth (say) = 0.10 m

Top width of flow area = 3.5 + 4 x 0.1 + 3 x 0.1 = 4.2 m

Cross-section area, A = 0.5 x 0.1 (3.5 + 4.2) = 0.385 m^2

Wetted perimeter, P = 3.5 + 0.1 (3.162 + 4.123) = 4.228 m

Hydraulic radius, R = A/P = 0.385/4.228 = 0.091 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$ (from Equation F.3)

$= (1/0.104)\ (0.385)\ (0.091^{2/3})\ (0.05^{1/2})$

$= 0.167\ m^3/s > 0.15\ m^3/s$, required

Try another depth slightly smaller than 0.10 m.

Trial 2:

Flow depth (say) = 0.09 m

Top width of flow area = 3.5 + 4 x 0.09 + 3 x 0.09 = 4.13 m

Cross-section area, A = 0.5 x 0.09 (3.5 + 4.13) = 0.343 m^2

Wetted perimeter, P = 3.5 + 0.09 (3.162 + 4.123) = 4.155 m

Hydraulic radius, R = A/P = 0.343/4.155 = 0.082 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$

$= (1/0.104)\ (0.343)\ (0.082^{2/3})\ (0.05^{1/2})$

= 0.139 m^3/s < 0.15 m^3/s, required

Hence, the actual depth of flow would be in between 0.09 m and 0.10 m. Take 0.10 m for simplicity in further calculations.

Step 2: Check the shear resistance of the gravel lining.

Trial 1:

Tractive shear stress of flow, $\tau_p = \delta\ d\ s$

= 9.81 x 0.10 x 0.05

= 0.049 kPa = 49 Pa

Permissible shear stress of 150 mm diameter rock riprap = 0.096 kPa = 96 Pa (from Table F.3(c)).

Hence, D_{50} = 150 mm diameter riprap is more than adequate.

Try using smaller rock size riprap if possible from cost-effective considerations.

Trial 2:

Assume riprap D_{50} = 50 mm = 0.050 m, corresponding Manning's n = 0.066 (from Table F.2)

Assume depth of flow = 0.075 m

Top width of the flow = 3.5 + 4 x 0.075 + 3 x 0.075 = 4.025 m

Cross-sectional area, A = 0.5 x 0.075 x (3.5 + 0.025) = 0.282 m^2

Wetted perimeter, P = 3.5 + 0.075 (3.162 + 4.123) = 4.045 m

Hydraulic radius, R = A/P = 0.282/4.045 = 0.0697 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$

$= (1/0.066) \times 0.282 \times 0.0697^{2/3} \times 0.05^{1/2}$

= 0.166 m^3/s > 0.150 m^3/s, required

Tractive shear stress of flow, $\tau_p = \delta\ d\ s$

= 9.81 x 0.075 x 0.05

= 0.036 kPa = 36 Pa

Permissible shear stress of 50 mm diameter rock riprap = 0.031 kPa = 32 Pa (from Table F.3(c)).

Hence, D_{50} = 50 mm riprap does not satisfy the limiting permissible shear stress values marginally.

Trial 3:

Try using riprap with slightly higher D_{50} = 60 mm.

To find permissible shear stress for D_{50} = 60 mm size rock, interpolate between the permissible shear stress values of 50 mm and 150 mm size rock (from Table F.3(c)).

$$\tau_p = 32 + (96 - 32)(60 - 50) / (150 - 50) = 38.4 \text{ Pa}$$

Hence, riprap with D_{50} = 60 mm is adequate.

Thickness of riprap lining = (1.5 to 2.0) D_{50}

= 90 to 120 mm

Use thickness of 100 mm of riprap with D_{50} = 60 mm

(Note: 100 mm is assumed since it is a simple fraction of a metre)

Example H.11 (Channel Protection – Riprap Lining)

Estimate the mean riprap diameter that will adequately convey a discharge of 0.5 m^3/s down a channel having 15% slope (Figure Example H.11). Assume the channel bed width is 1 m and the sideslope is 3:1. Also estimate the flow depth.

Solution:

Discharge, Q = 0.5 m^3/s Bed slope, s = 0.15 m/m

Bed width, w = 1.0 m Sideslopes = 3:1

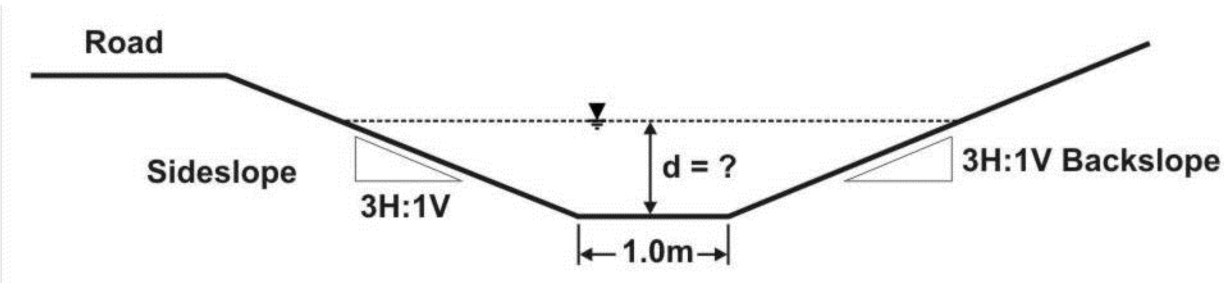


Figure (Example H.11): Typical Cross-Section

Enter Chart of Figure F.13, for, Q = 0.5 m^3/s

Flow depth = 180 mm

Riprap mean diameter D_{50} = 220 mm

Example H.12 (Channel Protection – Concrete Lining)

Design a concrete lining for a channel to carry a discharge of 1.5 m^3/s down a steep stable slope of 3H:1V (Figure Example H.12).

Solution:

Step 1: Find the depth of flow.

Trial 1:

Assume channel dimensions: Bed width = 1.0 m, Sideslope = 2:1, Flow depth = 0.3 m

Manning's n = 0.013 (from Table F.2) for 30 cm flow depth for concrete

Top width of flow area = 2 x 0.3 + 1.0 + 2 x 0.3 = 2.2 m

Flow cross-sectional area, A = (½) (0.3) (1.0 + 2.2) = 0.48 m^2

Wetted perimeter, P = 1.0 + 2 x 0.3 x 2.236 = 2.34 m

Hydraulic radius, R = A/P = 0.48/2.34 = 0.205 m

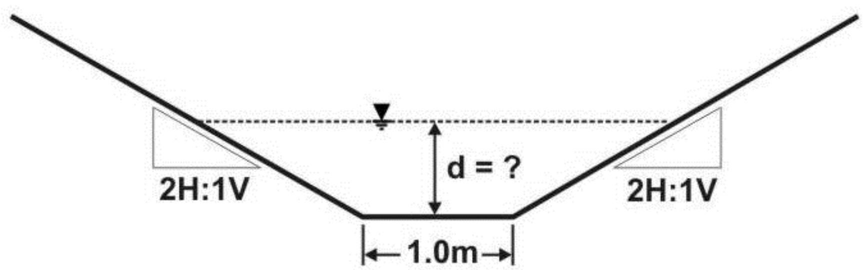


Figure (Example H.12): Typical Cross-Section

Discharge, Q (from Manning's equation)

$$Q = (1/n)\ A\ R^{2/3}\ s^{1/2} \text{ (Equation F.3)}$$

$$= (1/0.013)\ (0.48)\ (0.205^{2/3})\ (0.33^{1/2})$$

$$= 7.38\ m^3/s$$

This section is too large for the desired discharge, hence revise bed width and flow depth.

Trial 2:

Assume, Bed width = 0.5 m Flow depth = 0.2 m

Top width of flow area = 2 x 0.2 + 0.5 + 2 x 0.2 = 1.3 m

Cross-sectional area, A = (½) (0.2) (0.5 + 1.3) = 0.18 m^2

Wetted perimeter, P = 0.5 + 2 x 0.2 x 2.236 = 1.39 m

Hydraulic radius, R = A/P = 0.18/1.39 = 0.129 m

Discharge, Q $= (1/n)\ A\ R^{2/3}\ s^{1/2}$

$= (1/0.013)\ (0.18)\ (0.129^{2/3})\ (0.33^{1/2})$

$= 2.04\ m^3/s > 1.5\ m^3/s$, required by a slight margin

Hence, bed width = 0.5 m and Flow depth = 0.2 m are adequate.

Add freeboard = 0.2 m (equal to depth of flow), hence, required total depth of channel = 0.4 m

Example H.13 (Channel Protection – Gabion Mat Lining)

Estimate the rock size and gabion thickness required to discharge of 0.3 m^3/s down a channel with a 20% gradient (Figure Example H.13). Assume the bed width of the channel = 1.5 m and sideslopes = 3:1.

Solution:

Step 1: Find depth of flow.

Discharge, Q = 0.3 m^3/s   Bed slope, s = 0.20 m/m

Bed width, w = 1.5 m   Sideslopes = 3:1

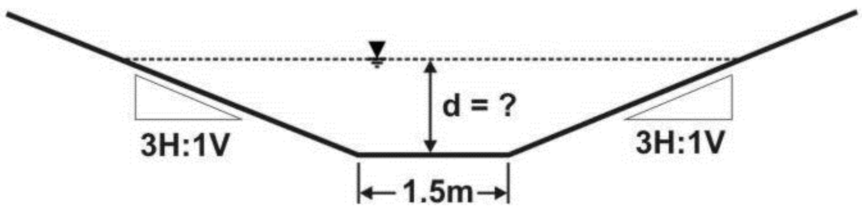


Figure (Example H.13): Typical Cross-Section

Enter Chart of Figure F.20, for Q = 0.3 m^3/s, and Flow depth = 90 mm

Step 2: Determine the size of gabion filling rock.

Tractive shear stress of flow, $\tau_p = \delta$ d s

τ_p = 9.81 x 0.090 m x 0.20

= 0.176 kPa = 3.676 lbs/ft^2 (assume 1 kPa = 20.886 lbs/ft^2)

From Figure F.15, for τ_p = 0.176 kPa, mean rock size diameter = 0.5 ft = 150 mm

Step 3: Find thickness of gabion mattress:

a) From Figure F.16, for τ_p = 0.176 kPa

Minimum thickness = 0.25 ft = 0.076 m

b) From the guidelines mentioned in Section F17.1

Mattress thickness = (2 to 3) times D_{50}

= 300 mm to 450 mm if D_{50} = 150 mm rock used

c) Gabion mattress thickness as manufactured is from 0.25 m to 0.45 m

Hence, adopt 0.30 m thickness, which is close to 2 times D_{50}.

Example H.14 (Flow Depth Estimation)

What would be the flow depth in Example H.11, if the sideslope is 4H:1V (Figure Example H.11)?

Solution:

From Example H.11, flow depth = 180 mm = 0.180 m bed width = 1.0 m

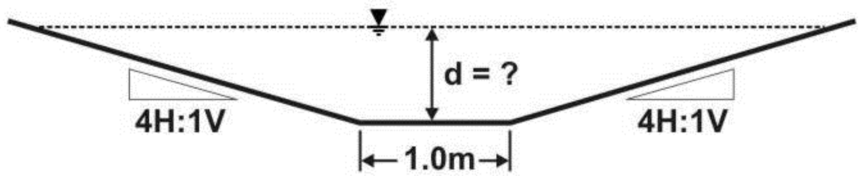


Figure (Example H.14): Typical Cross-Section

Top width of flow area = 1.0 + 3 x 0.180 + 3 x 0.180 = 2.08 m

Area of flow = 0.5 x 0.180 (1.0 + 2.08) = 0.277 m^2

Let d be the depth of flow, then top width of flow = 1.0 + 4d + 4d = 8d + 1

Area of cross-section = 0.5 x d x (8d + 1 + 1) = $4d^2 + d$

Equating the areas of 3:1 and 4:1 sideslope of the ditch configurations, $4\ d^2 + d = 0.277\ m^2$

Solving the equation for d, d = 0.163 m < 0.180 m, marginally

Example H.15 (Sediment Storage Capacity for Sediment Barriers)

Assume a typical secondary highway roadside ditch section with the geometric properties given below (Figures Example H.15a and H.15b). Determine the appropriate ditch barrier spacing to control the sediment loss from the site. Assume a mean annual sediment yield of 40 m^3/ha.

Bed width = 3.5 m	Barrier height = 0.5 m	Backslope = 3:1 (horiz : vert)
Ditch grade = 4%	Ditch depth = 1 m	Sideslope = 4:1 (horiz : vert)

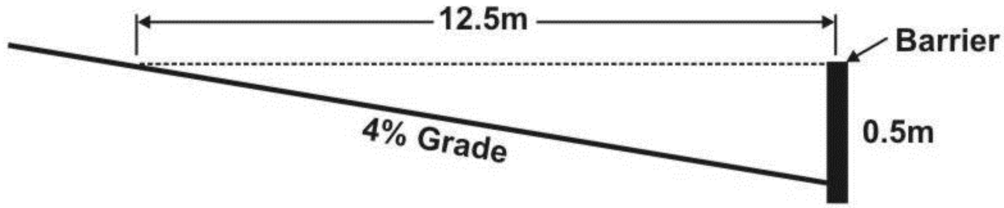


Figure (Example H.15a): Longitudinal Profile

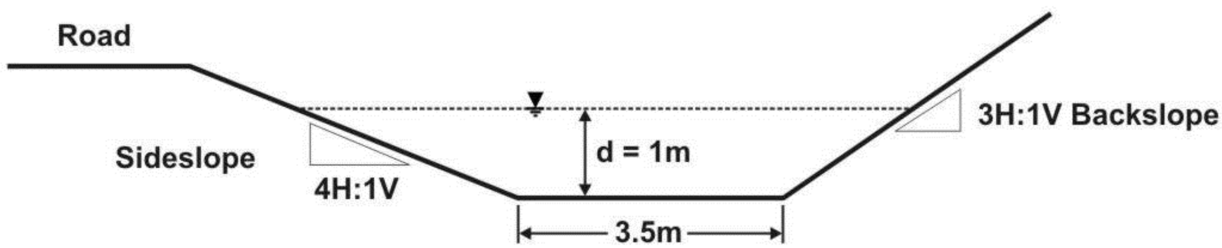


Figure (Example H.15b): Cross-Section

Solution:

Step 1: Calculate the length of sediment spread behind a barrier.

Since the ditch grade is 4% and the height of a barrier is 0.5 m, the sediment will be stored over a ditch length of 12.5 m behind the barrier.

Also, note that, while calculating the likely sediment volume behind a barrier, the cross-section of the deposited sediment changes from one location to another within this 12.5 m distance.

Step 2: Calculate the volume of sediment storage behind a barrier.

From Figure H.15a,

Top width of the storage area at the barrier = 3.5 + 4 x 0.5 + 3 x 0.5 = 7 m

Top width of storage at 12.5 m away from and behind the barrier = 0 m

Area of cross-section at the barrier = 0.5 x 0.5 x (3.5 + 7.0) = 2.625 m^2

Area of cross-section 12.5 m behind the barrier = 0.0 m^2

Hence, volume of storage (assuming a linear variation between the two locations)

= 0.5 x (2.625 + 0) x 12.5 = 16.4 m^3

Assume only half of this volume is allowed to be filled up by sediment. Reason: the remaining will be like a buffer space for erosion during unanticipated very heavy rainfall seasons or, if cleaning is done in alternate years.

Hence, sediment volume likely to be deposited behind a barrier = 8.2 m^3

Area served by one barrier = 8.2/40 = 0.205 ha

Likely width of disturbed area = 6+ 4 x 1 + 3.5 +12.6 = 26.1 m (from Figure H.15c), assuming the ground is disturbed up the backslope by a distance of 12.6 m.

Note: 1 ha = 10,000 m^2

Hence, spacing = 0.205 x 10,000/26.1 = 78.5 m, say, 75 m spacing for convenience of construction. For practical and conservative purposes, a spacing of 60 m (every 3 stations of 20 m) can be considered.

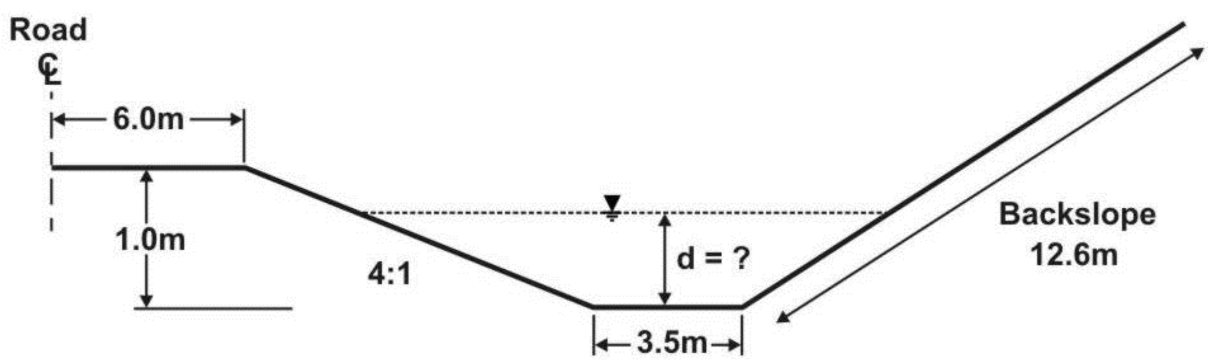


Figure (Example H.15c): Cross-Section Profile up the Backslope

Example H.16 (Design of Sedimentation Pond/Trap)

In the Peace River area, the construction of a highway alignment down a river valley exposed a cutslope of 3 hectare area of bare soil surface. The average cutslope is a single slope at 3H:1V and 25 m length. The cutslope was stipulated for surface texturing with track walking up/down slope. The contactor will schedule to excavate the slope to follow with topsoiling and seeding within the 3 months of July, August and September. The alignment traverses the river course and there is direct connectivity to a fish bearing stream of high environmental sensitivity. The soil types of the area consist of 60% silty low plasticity clay (ML to CL) and 40% high plasticity clay (CH). No rainfall gauge station is available for the immediate area and the hydraulic/hydrotechnical engineer's assessment on inflow runoff quantity into the sedimentation pond is not available. Soil sampling of the ML soil was undertaken at mid height of cutslope and a hydrometer gradation analysis of the ML soil was carried out in preliminary recognition of the erodibility of the ML material.

Hydrometer Gradation (see Figure Example H.16c)

Soil Particles	Percent	Other USCS Properties (Figure 4.1)	
Clay	14	Plasticity Index	PI = 10%
Silt	43	Liquid Limit	LL = 24%
Sand	41	ML to CL material	
Gravel	2		

Note: This design follows the design approach of Fifield 2001 with engineering modifications.

Questions:

1) **What is preliminary soil erodibility assessment?**

2) **What is the amount of erosion sediment from the cutslope?**

3) **What is the hazard rating of the site; appropriate action if required?**

4) **If sedimentation pond is required, what storage volume of sediment laden runoff can be anticipated?**

5) **How to develop the requirement for the design of a sedimentation pond?**

6) **Design of sedimentation control (as a perimeter control measure adjacent to high risk area).**

Question (1): Evaluate the preliminary soil erodibility:

Determine preliminary Soil Erodibility based on USCS from Figure 4.2.

For CH soil, soil erodibility is considered LOW – no concern

For ML soil, soil erodibility is considered HIGH – concern

Answer: For ML soil, erodibility is considered **HIGH** (Figure 4.2) and of concern

Hydrometer gradation analysis is necessary

Question (2): What is the amount of erosion sediment (SOIL LOSS) from the cutslope?

Construction Conditions:

a) Erodible Soil Distribution Area: 60% of the area is ML soil of high erodibility

b) Construction Schedule 3 months: Soil Erodibility (K) reduction by 35%

(July + Aug + Sept = 41 + 17 + 7 = 65% of annual Erodibility Factor (R))

SOIL LOSS (A): evaluate using RUSLE formula (Equation 6.1) with highway modification factors

$RUSLE_{highway}$

$$A = R \times K_{highway} \times LS_{highway} \times C \times P \qquad \text{(Equation 6.1)}$$

= 325 x 0.07 x 4.1 x 1 x 0.9

= 84 tonne/ha/yr Soil Loss Hazard: very high (Table 6.1)

x 0.6 erodible soil distribution area in (a)

x 0.65 construction schedule time distribution per year in (b)

Therefore,

$A_{construction\ period}$ = 84 x 0.6 x 0.65

= 32 tonne/ha/construction period Soil Loss Hazard = high (Table 6.1)

Where:

R = 325 MJ mm ha^{-1} h^{-1} y^{-1} (Figure B-1; Appendix B)

$K_{agriculture}$ = 0.088 MJ^{-1} mm^{-1} tonne hr (Figure B-5; Appendix B)

$K_{highway}$ = 0.070 ($K_{agriculture}$ x 0.8 (highway modification factor $Ø_K$) see Section 6.2.2.2)

% silt + sand = 84 (use 70%; maximum value in Figure B-5; overestimation of K is possible)

% sand = 41

% OM = 1 (assume 1 for using Figure B-5)

Soil Structure = 4 (blocky, platty, massive)

Permeability = 3 (slow to moderate)

$LS_{agriculture}$ = 5.2 (Table B-3; Appendix B)

$LS_{highway}$ = 4.1 ($LS_{agriculture}$ x 0.8 (highway LS modificator factor $Ø_{LS}$) see Section 6.2.3.2)

Single slope

33% Slope (3H:1V)

Slope length = 25 m

C = 1 (Table B-6a; bare soil with no mulch)

P = 0.9 (Table B-7; bare soil freshly rough)

Answer: SOIL LOSS (A)

A_{annual} = 84 tonne/ha/yr

$A_{construction\ period}$ = 32 tonne/ha/construction period

Question (3): What is the hazard rating of the site?

Answer:

A_{annual}	= 84 tonne/ha/yr	Soil Loss Hazard: Very High (Table 6.1)
$A_{construction\ period}$	= 84 x 0.6 x 0.65	
	= 32 tonne/ha/construction period	Soil Loss Hazard: High (Table 6.1)

Answer:

The rating of soil loss hazard per year is very high:

- Therefore scheduling of construction to minimize bare soil exposure and speedy topsoiling and seeding are required to lower the annual soil loss hazard rating.
- The rating of soil loss hazard per construction season is still high after scheduling of the construction.
- Therefore the design of sediment pond at perimeter of site is required.

Question (4): If sedimentation pond is required, what storage volume of sediment laden runoff can be anticipated? How to develop the requirements of a sedimentation pond?

If available runoff estimate is not available, it is appropriate to use 250 m^3/ha of disturbed soil areas for estimating storage volume of sedimentation pond. This is based on 25 mm runoff per hectare (EPA requirements; (Fifield 2001)). The 25 mm runoff per hectare is appropriate for 40 to 45 mm precipitation over loamy clay (Type C) to clay (Type D) (see Figure 4.5).

In areas of severe land constraint, a minimum size of sedimentation pond at 150 m^3/ha of disturbed land may be considered in accordance with the risk level of the site. Thus, a pond size of 450 m^2 may be a minimum requirement for 3 ha of land disturbed.

Answer:

A 750 m^3 storage volume as preliminary estimate is appropriate for 3 ha of disturbed area.

Question (5): How to develop the requirement for the design of a sedimentation pond?

The following parameters should be available.

Steps to determine:

1) Target size particle (D_s) for settlement performance
2) Settling velocity (V_s) of target size particle (D_s)
3) Outflow (Q_o) performance and capacity of outflow structure of Sedimentation Pond

4) (i) Inflow (Q_i) Runoff Estimation based on affected area, and (ii) Estimate of Width (W) requirement of outflow structure
5) What is surface area (SA) of sedimentation pond using 1m retention depth?
6) What is gradation (PEG) of the material coarser than the target size particle for sedimentation?
7) What is the efficiency of the sedimentation pond?

Step 1: Target size particle (D_s) for settlement

D_s = 0.03 mm medium size silt is targeted for sedimentation.

Step 2: Settling velocity (V_s) of target size particle

Result:

V_s = 0.06 cm/s for D_s = 0.030 mm size medium silt particles @ 10°C water temperature (Table G.1)

Step 3: Outflow performance and outflow capacity (Q_o) of Sedimentation Pond

The outflow capacity (Q_o) of sedimentation seepage flow from outflow structure of a sedimentation pond can be more accurately assessed with the use the following properties of construction material and design geometry (Refer to Figure G.3a for pictorial of the following dimensional properties).

1) porosity (ρ) and permeability of filter system
2) average rock diameter (D) of gravel berm
3) width (W) of permeable berm
4) flow length (T) through filter system
5) height (H) of water under retention

Equation G.4 (proposed by Jiang et al., 1998) on relationship on outflow performance provides reasonable results for a permeable berm outlet system was considered appropriate for use in sedimentation retention (Fifield, 2001). See Section 12 for details.

$$Q_o = 0.327\, e^{1.5S} (g\, D_{50} / T)^{0.5}\, \rho W\, H^{1.5} \qquad \text{(Equation G.4)}$$

(Jiang et al., 1998)

Where:

Q_o = Outflow capacity of containment system (m^3/s)

g = Acceleration due to gravity = 9.8 m/s^2

D_{50} = Mean diameter of the rock (m); for this equation

W = Total width of the barrier (m)

ρ = Porosity of the rock barrier

T = Thickness of the barrier (m)

H = Hydraulic head (m)

S = Slope of channel (%) (generally varies from 0% to 7% for highway gradeline profiles)

The concept of Equation G.4 is presented in Figure G.3 and a typical detail of permeable gravel outlet berm option is presented in Figure G.4.

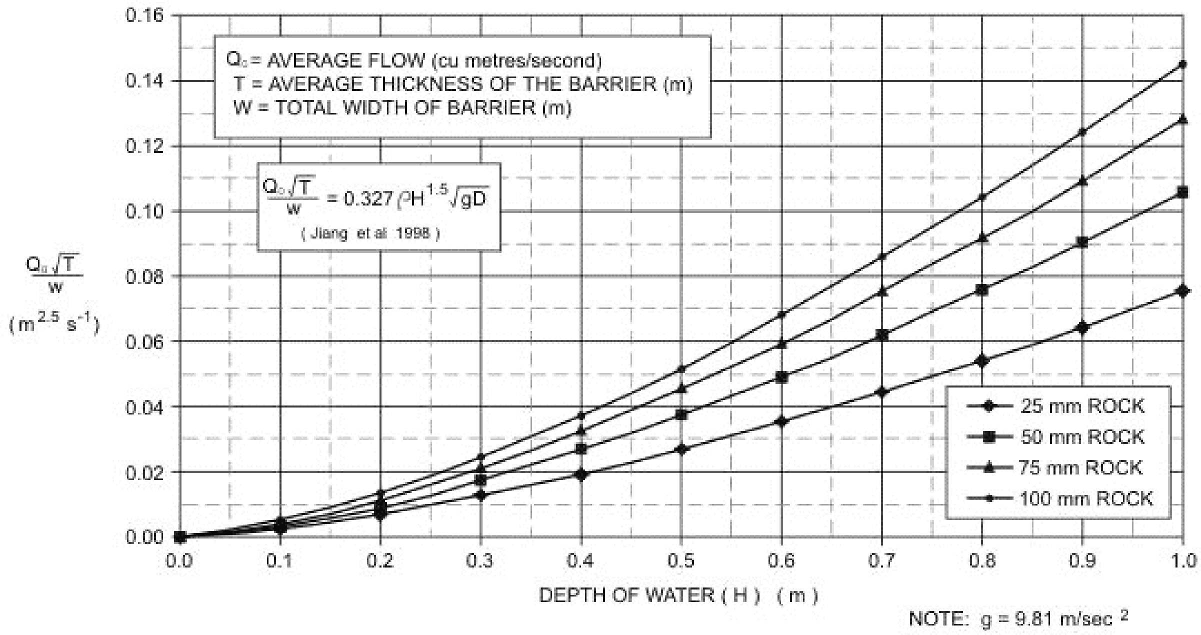


Figure (Example H.16a)

Figure G.3b: Flow (Q) through an Outlet Barrier (g) of various Diameter (D) Rocks in Gabion Basket

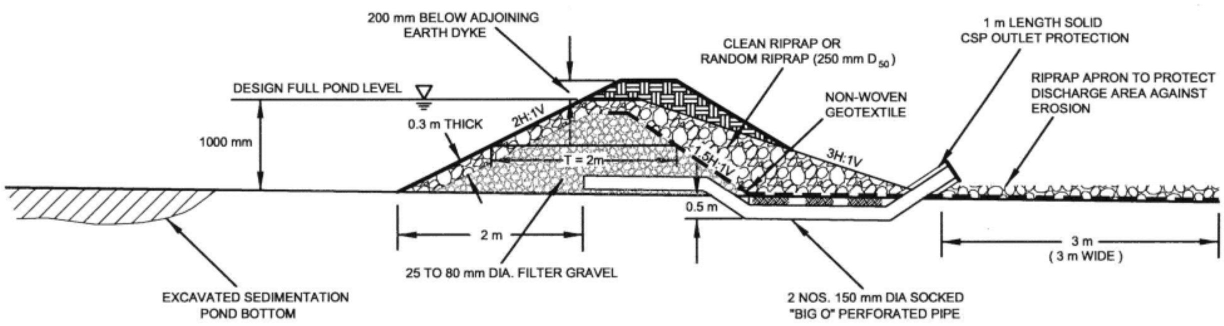


Figure (Example H.16b)

Figure G.4: Typical Sedimentation Basin/Trap Outlet Permeable Structure with Rock Filter Barrier and Perforated Pipe

From Figure Example H.16a (Figure G.3b), a derived version outflow capacity ($Q_o\ T^{0.5} \div W$) result of sedimentation pond outlet construction of permeable gravel berm can be read off. The outflow (Q_o) can be calculated from construction parameters as follows:

Assumed typical parameters and properties of permeable rock berm:

Porosity (ρ) = 0.45

Gravel berm average clean rock size (D) = 80 mm = 0.08 m

Average width of berm (W) - W to be determined

Average thickness of berm (T) = 2 m (see Figure Example H.16b) (i.e., Figure G.4)

Maximum height of runoff retention = 1 m

Thus, from Figure Example H.16a (Figure G.3b):

for H = 1m

$Q_o\ T^{0.5} \div W = 0.11\ (m^{2.5}\ s^{-1})$

Where:for T = 2 m

$$Q_o = \frac{0.11W}{1.41} = 0.08W$$

Results:

Outflow capacity (Q_o) of permeable gravel berm $Q_o = 0.08W\ m^3\ s^{-1}$

Step 4: i) Inflow runoff estimation based on affected area

ii) Estimate of width requirement of outflow structure

The hydrologist or hydrotechnical engineer should assess the terrain drainage and the affected area of construction to assess the amount of sediment laden inflow runoff (Q_i) into the sedimentation pond area. The inflow is compared with the estimate outflow capacity (Q_o) of the permeable outlet to design the width (W) of the permeable outlet.

use: $Q_i = 0.5\ m^3\ s^{-1}$ (assumed)

at full storage: $Q_o = Q_i = 0.5\ m^3\ s^{-1}$

then for: $Q_o = 0.08W$

$W = 6.3$ m

Results:

For pragmatic design consideration for permeable outlet, a practical outlet width (W = 6.3 m) can be considered to provide an outflow capacity ($Q_o = 0.5\ m^3/s$).

Step 5: What is surface area of sedimentation pond

It is appropriate to consider:

1) inflow (Q_i) equal to outflow (Q_o) (in Step 4)

$$Q_i = Q_o \qquad \text{(Equation G.3)}$$

2) and/or minimum storage volume of 250 m^3 /ha disturbed land for design of sedimentation pond

Thus, Inflow Runoff Volume (Q_o) = 0.5 $m^3\ s^{-1}$ (from step 4), then find surface area of pond (SA)

Pond Surface Area:

$$SA = 1.2\ Q_o \div Vs \qquad \text{(Equation G.5)}$$

$$= 1.2\ (0.5\ m^3\ s^{-1}) \div 0.0006\ cm/s$$

$$= 1000\ m^2$$

Where: V_s = 0.06 cm/s = 0.0006 m/s (see step 1)

Step 6: What is Percentage Material Equal to or Greater (PEG) (i.e., gradation of the material coarser than the target size particle for sedimentation)

From hydrometer gradation curve results (see Figure Example H.16c) for:

Where:

D_s = 0.03 mm medium to fine size silt as target size particle

PEG = 55% (or 45% smaller in hydrometer gradation curve)

Step 7: What is the efficiency and design of the sedimentation pond?

Apparent efficiency (A_{eff}) can be determined by configuration of sedimentation using L/We ratio concepts.

Net efficiency (N_{eff}) is the combined effect of pond configuration settling velocity of target size particle as assessed in PEG.

$$N_{eff} = A_{eff} \times PEG \qquad \text{(Equation G.11)}$$

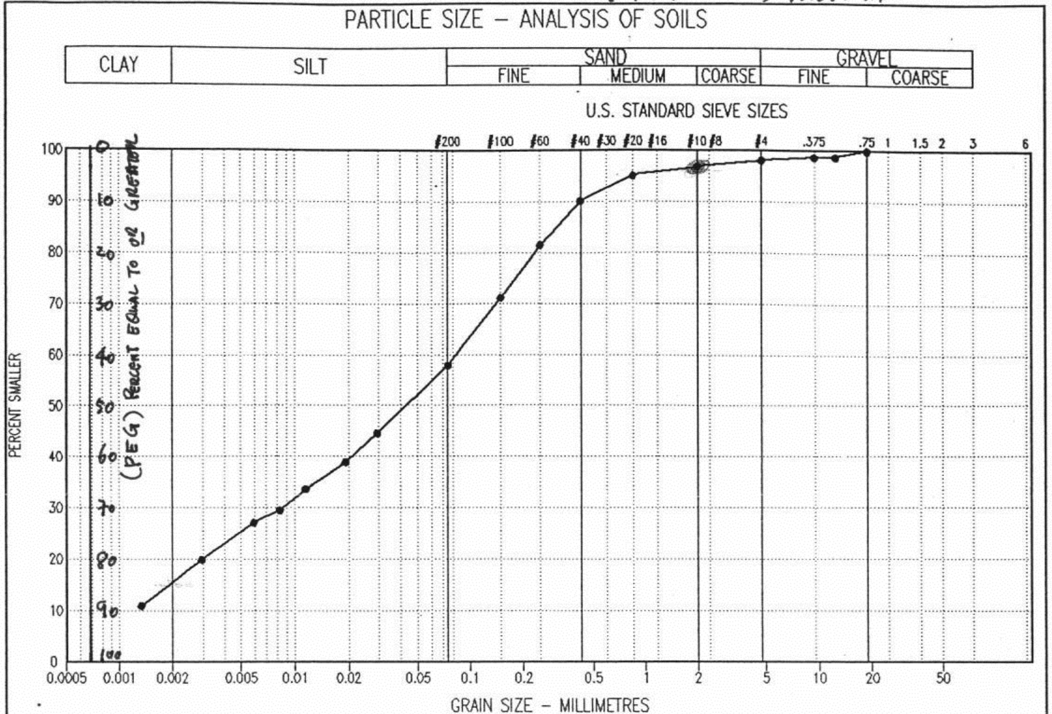
$$= 0.92 \times 0.55$$

$$= 50\%$$

Where : A_{eff} = 92% using L/We = 7 (Figure G.7)

PEG = 55% for D_S = 0.03 mm (medium to fine silt) (Step 6)

EBA Engineering FIGURE EX 14.16 PEG (GRADATION) ASSESSMENT



SYMBOL	BOREHOLE NUMBER	DEPTH (m)	DESCRIPTION CLAY %	SILT %	SAND %	GRAVEL %	Cu	Cc	U.S.C
●——●	4	32.50 – 33.50	14.0	43	41	2	–	–	

Project: 0104–7100023 Date Tested: 02/03/14 BY: SK

Tested in accordance with ASTM D422 unless otherwise noted.

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Figure (Example H.16c): PEG (Gradation) Assessment

Results:

Design of Sedimentation Pond (Figures 12.1, G.3a and G.4)

1) Medium size silt (D = 0.03 mm) as design particle for settlement efficiency goal
2) L/We ratio = 7 (Figure 12.1)
3) Pond area = 1000 m²; flow chamber width (We) = 12 m; chamber length (L) – 84 m (Figure 12.1)
4) Earth dyke height = 1.2 m (Figure G.3a and G.4)

(5a) Outlet berm height = 1.0 m (Figure G.3a and G.4)

(5b) Outlet berm width (W) = 6.3 m

6) Outlet berm average thickness = 2 m (Figure G.4)
7) Outlet berm average rock size (D) 100 mm diameter
8) Apparent Efficiency (A_{eff}) = 92%
9) Net Efficiency (N_{eff}) = 50%