1 Riprap Design

Determine the size, thickness, and gradation of the rip rap blanket required for the stabilization of the outer bank of the channel with the following parameters.

Given channel parameters:
Specific weight of stone, $\gamma_s = 26 \text{kN/m}^3$.
Local depth at toe of outer bank, $d_{toe} = 7.6$ m
Local depth at 20 percent upslope from toe, $d_{upslope} = 6.1$ m
Channel side slope = 1V:2H = $\theta = 0.4636$ rad
Downstream channel slope: $S_0 = 0.00038$
Minimum centerline bend radius: $R_b = 520$ m
Average flow velocity, $V = 2.2$ m/s Surface channel width, $W = 150$ m

Assume the following values: Specific weight of water, $\gamma = 9810$ N/m^3
Angle of repose of material, $\phi = 40° = 0.698$ rad.
For stability analysis, $M/N \approx 5$
We will assume that the flow depth for the riprap placement is d_{toe}.

1.1 Sizing

Solving for the following hydraulic parameters:

$$A = Wh = (150\,m)(7.6\,m) = 1140\,m^2 \tag{1}$$

$$P = W + 2h = 150\,m + 2(7.6\,m) = 165.2\,m \tag{2}$$

$$R_h = A/P = 1140\,m^2/165.2\,m = 6.9\,m \tag{3}$$

$$\tau_0 = \gamma R_h S = (9810\,n/m^3)(6.9\,m)(0.00038) = 25.72\,Pa \tag{4}$$

Sharp bend correction factor:

$$K_b = 1 + 2W/R_b = 1 + 2(150\,m)/(520\,m) = 1.577 \tag{5}$$

Solving for the representative riprap diameter using the shear-stress equation:

$$d_m = \frac{K_b \tau_0}{\sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}} \times 0.047(\gamma_s - \gamma)} = \frac{(1.577)(25.72\,Pa)}{\sqrt{1 - \frac{\sin(0.467)^2}{\sin(0.698)^2}} \times 0.047(26000\,N/m^3 - 9810\,N/m^3)} \approx 75\,mm \tag{6}$$

1.2 Safety factor calculation

$$\eta_0 = \frac{25.72\,Pa}{(2.65-1)*(1000\,kg/m^3)*(0.075\,m)*0.047} = 0.456 \tag{7}$$

$$\Theta = \tan^{-1}(\sin(0.00038)/\sin(0.467)) = 0.00085\,rad \approx -0.049^\circ \tag{8}$$

$$a_\Theta = \sqrt{\cos(0.467)^2 - \sin(0.00038)^2} = 0.894 \tag{9}$$

$$\lambda = -\tan^{-1}\left(\frac{11 * 6.9\,m}{520\,m}\right) = -0.145\,rad \approx -8.31^\circ \tag{10}$$

$$\beta = \tan^{-1}\left[\frac{\cos(-0.145+0.00085)}{\frac{6\sqrt{1-(0.894^2)}}{0.456tan(0.698)} + \sin(-0.145+0.00085)}\right] \approx 0.143\,rad \approx 8.19^\circ \tag{11}$$

$$\eta_1 = \eta_0\left[\frac{5+\sin(-0.145+0.143+0.00085)}{6}\right] = 0.38 \tag{12}$$

$$SF = \frac{0.894\tan(0.698)}{(0.38)\tan(0.698) + \sqrt{1-(0.894^2)}\cos(0.143)} \approx \mathbf{0.986} \tag{13}$$

Because the SF is slightly less than 1, we will consider the 75 mm riprap unstable for the given channel bend characteristics, and **increase d_m to 100 mm. This results is a SF of 1.105**. Therefore, this size of riprap can be ensured to be stable for the given channel bend characteristics.

1.3 Thickness

Following guideline of Julien 2018, the chosen riprap blanket **thickness is 300 mm**.

1.4 Gradation

The riprap gradation is chosen for $d_{65} \approx$ 100 mm, equating to $d_{50} \approx$ 80 mm. A gradation curve for the recommended riprap material sizing, in accordance with guidance from Richardson, Simons, and Lagasse 2001 is shown in Fig. 1.

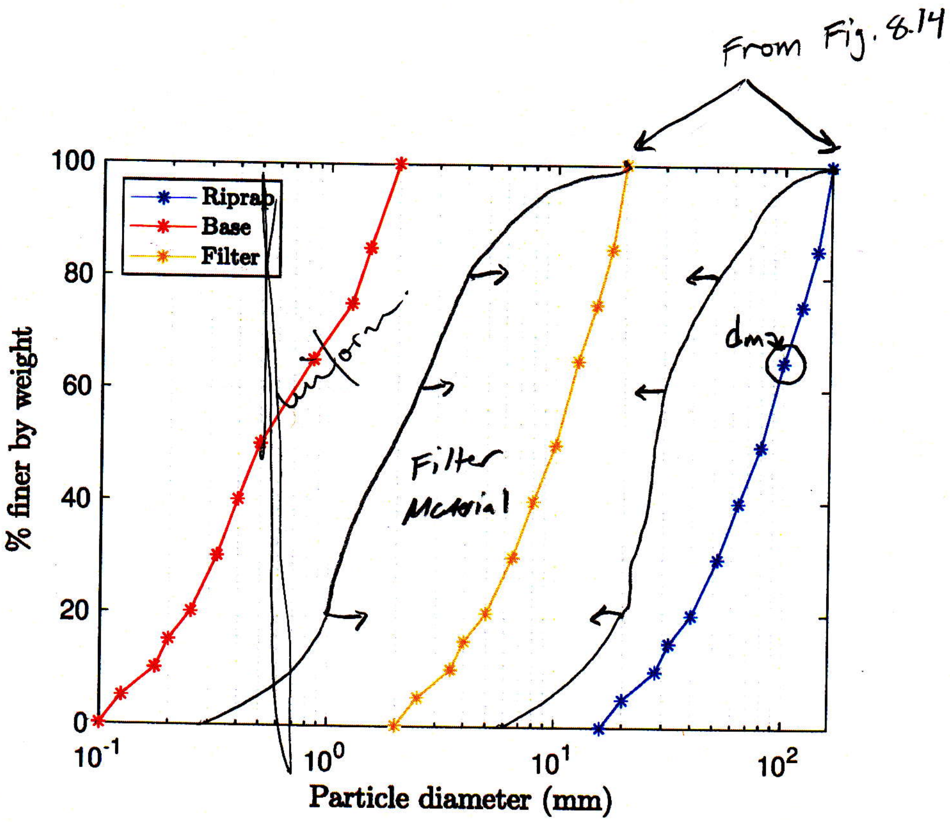


Figure 1: Gradation curve for riprap design, with $d_m \approx 100$ mm.

1.5 Gravel filter design

If the riprap is placed over uniform 0.5 mm sand, design the gravel filter required to prevent leaching.

Table 1: Size of materials for riprap design

Base material sand	Riprap
$d_{85} = 1.5$ mm	$d_{85} = 140$ mm
$d_{50} = 0.5$ mm	$d_{50} = 80$ mm
$d_{15} = 0.17$ mm	$d_{15} = 32$ mm

For designing the filter according to the base material:

$$5(0.17\,mm) < d_{15_{filter}} < 40(0.17\,mm) \rightarrow 0.85\,mm < d_{15_{filter}} < 6.8\,mm \tag{14}$$

$$d_{50_{filter}} < 40(0.5\,mm) \rightarrow d_{50_{filter}} < 20\,mm \tag{15}$$

For designing the filter according to the riprap material:

$$1/40(30\,mm) < d_{15_{filter}} < 1/5(30\,mm) \rightarrow 0.75\,mm < d_{15_{filter}} < 6\,mm \tag{16}$$

$$d_{50_{filter}} > 1/40(80\,mm) \rightarrow d_{50_{filter}} > 2\,mm \tag{17}$$

$$d_{85_{filter}} > 1/5(30\,mm) \rightarrow d_{85_{filter}} > 6\,mm \tag{18}$$

Problem 2

Subject: Downstream Hydraulic Geometry

Given – Problem 10.2

Irrigation canal that conveys 5,000 cfs in a very fine gravel- bed channel.

Find

A. Use the regime relationships to calculate the hydraulic geometry of the irrigation canal.
B. Compare with the hydraulic geometry for stable channels.

Methods/Solution

A. Regime Relationship (Assuming ds = 3 mm)
   a. Lacy Silt Factor

$$f_l \simeq 1.59ds^{1/2} = 1.59(3mm)^{1/2} = 2.75$$

   b. Velocity

$$V = 0.794Q^{1/6}f_l^{1/3} = 0.794(5{,}000cfs)^{1/6}(2.75)^{1/3} = 4.6ft/s$$

   c. Hydraulic Radius

$$R_h = 0.47Q^{1/3}f_l^{-1/3} = 0.47(5{,}000cfs)^{1/3}(2.75)^{-1/3} = 5.74ft$$

   d. Area

$$A = 1.26Q^{5/6}f_l^{-1/3} = 1.26(5{,}000cfs)^{5/6}(2.75)^{-1/3} = 1087.43ft^2$$

   e. Wetter Perimeter

$$P = 2.66Q^{1/2} = 2.66(5{,}000cfs)^{1/2} = 188.1ft$$

   f. Slope

$$S = 0.00053f_l^{5/3}Q^{-1/6} = 0.00053(2.75)^{5/3}(5{,}000cfs)^{-1/6} = 6.9x10^{-4}$$

B. Hydraulic Geometry for Stable Channels – Julien and Wargadalam (1995)
   (Assuming Manning-Strickler, ds = 3 mm, τ* = 0.047)
   a. Depth

$$h \approx 0.133Q^{0.4}\tau_*^{-0.2} \approx 0.133(141.58cms)^{0.4}(0.047)^{-0.2} = 1.78m = 5.84ft$$

   b. Width

$$W \approx 0.512Q^{0.53}d_s^{-0.33}\tau_*^{-0.27} \approx 0.512(141.58cms)^{0.53}(.003m)^{-0.33}(0.047)^{-0.27}$$

$$W \approx 109.7m = 360ft$$

c. Velocity

$$V \approx 14.7Q^{0.07} d_s^{0.33} \tau_*^{0.47} = 14.7(141.58cms)^{0.07}(.003m)^{0.33}(0.047)^{0.47}$$

$$V \approx 0.73m/s = 2.4ft/s$$

d. Slope

$$S \approx 12.4Q^{-.4} d_s \tau_*^{1.2} = 12.4(141.58cms)^{-.4}(.003m)(0.047)^{1.2} = 1.3x10^{-4}$$

C. Comparison

Assuming that this system is a wide and shallow channel, Rh ≈ h and P ≈ W. See the table below for a comparison of the hydraulic geometries. The calculated depths were almost identical, and the slopes have the same relative magnitude, however, the width and the velocities were not similar. Though they both were off by a factor of 2, which makes sense because both of those parameters are inversely related in the equation Q=WhV.

Hydraulic Geometry	Regime Relationships	Julien and Wargadalam
h	5.74 ft	5.84 ft
W	188.1 ft	360 ft
V	4.6 ft/s	2.4 ft/s
S	6.9×10^{-4}	1.3×10^{-4}

Problem 3 (Prob. 10.9 in textbook): River Meandering

Given

Consider the aerial photo of the Red River in Figure P10.7. Locate the channel centerline in the downstream direction, plot theta as a function of the curve. Define the: valley length λ, river meander length L, sinuosity Ω, maximum deviation angle θ_m and meander width W_m. Compare with various plots of this chapter.

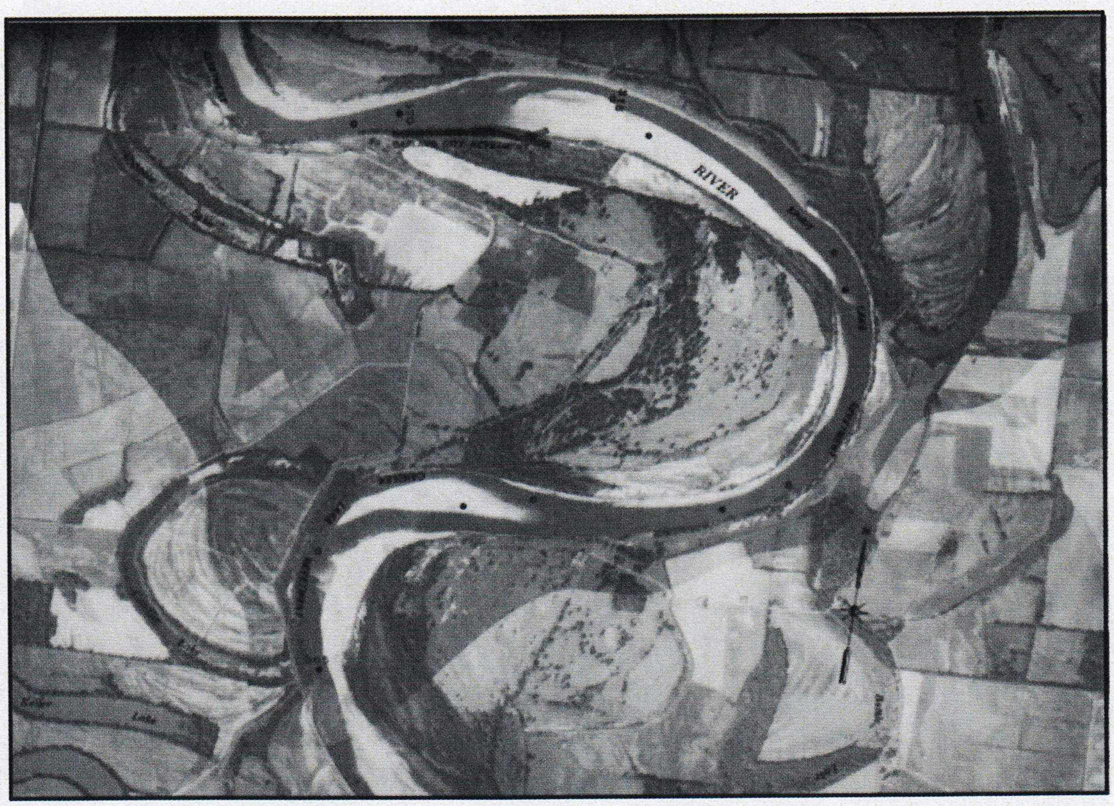


Figure P10.7. Reach of the Red River in Louisiana

Methods

Using google earth, the location shown in figure P10.7 was found, measurements of the valley length λ, river meander length L, sinuosity Ω, maximum deviation angle θ_m and meander width W_m were taken and are shown in figure 1 and table 1. The measured values are plotted against a sin-generated curve that is a function of the maximum deviation angle, see equation 1.

$$\theta = \theta_m cos\frac{2\pi x}{L} \qquad (1)$$

Where:

θ = Channel deviation angle at position x from upstream to downstream

x = Distance along the river meander length, L.

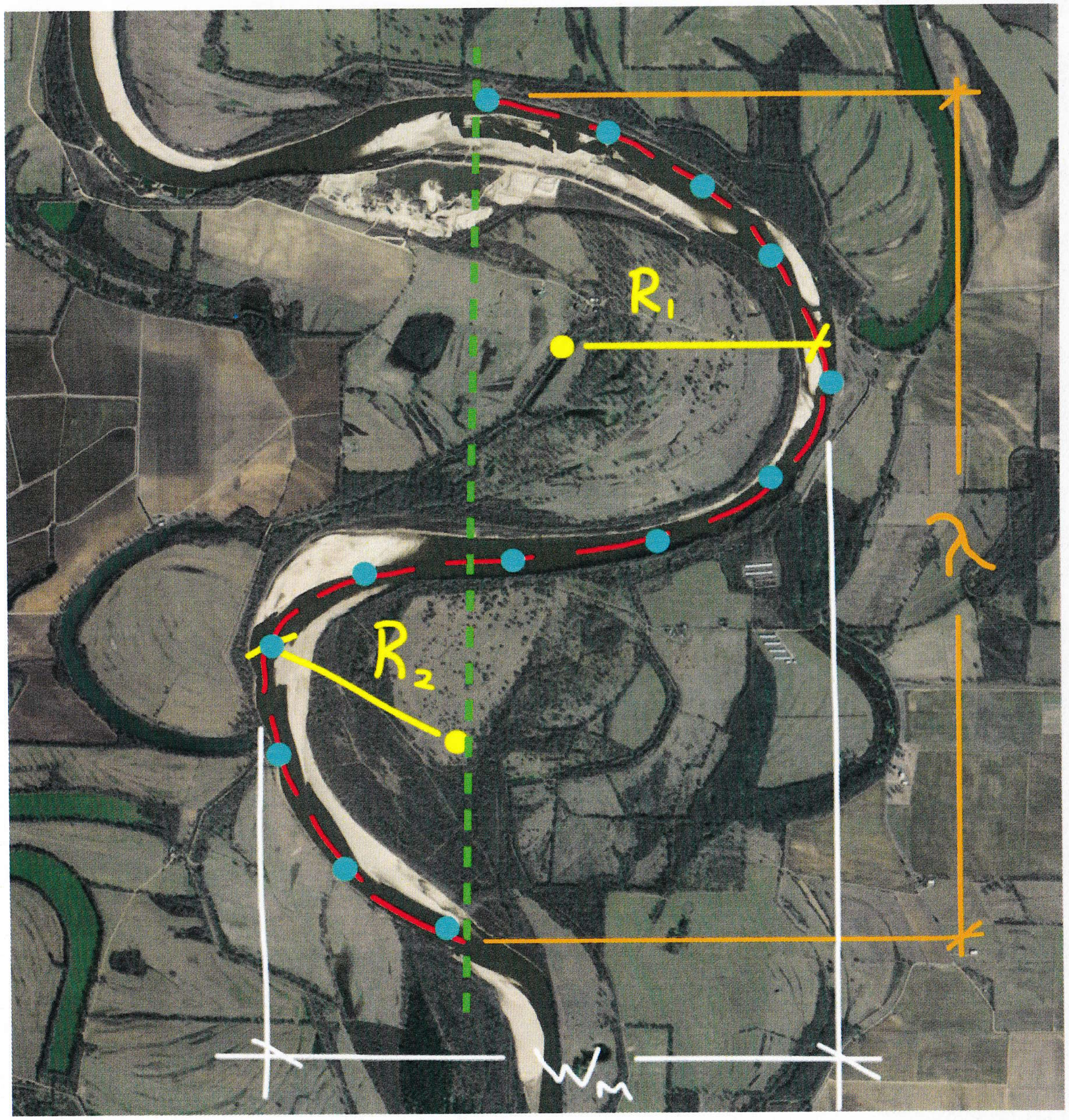


Figure 1. Red River meandering planform geometry

Table 1. Estimated river meander parameters

Parameter	Estimation
λ	5,000 m
W_m	3,200 m
L	9,000 m
R_1	1,400 m
$R_2 = R_{min}$	1,100 m
$\Omega = L/\lambda$	1.8
W_m/λ	0.64
λ/R_{min}	4.5

Table 2. Channel position and estimated deviation angle

Position	X [m]	Theta
1	0	75
2	800	60
3	1400	45
4	2000	20
5	2800	0
6	3400	-25
7	4200	-60
8	5000	-75
9	6000	-45
10	6750	0
11	7400	20
12	8000	40
13	9000	70

Results

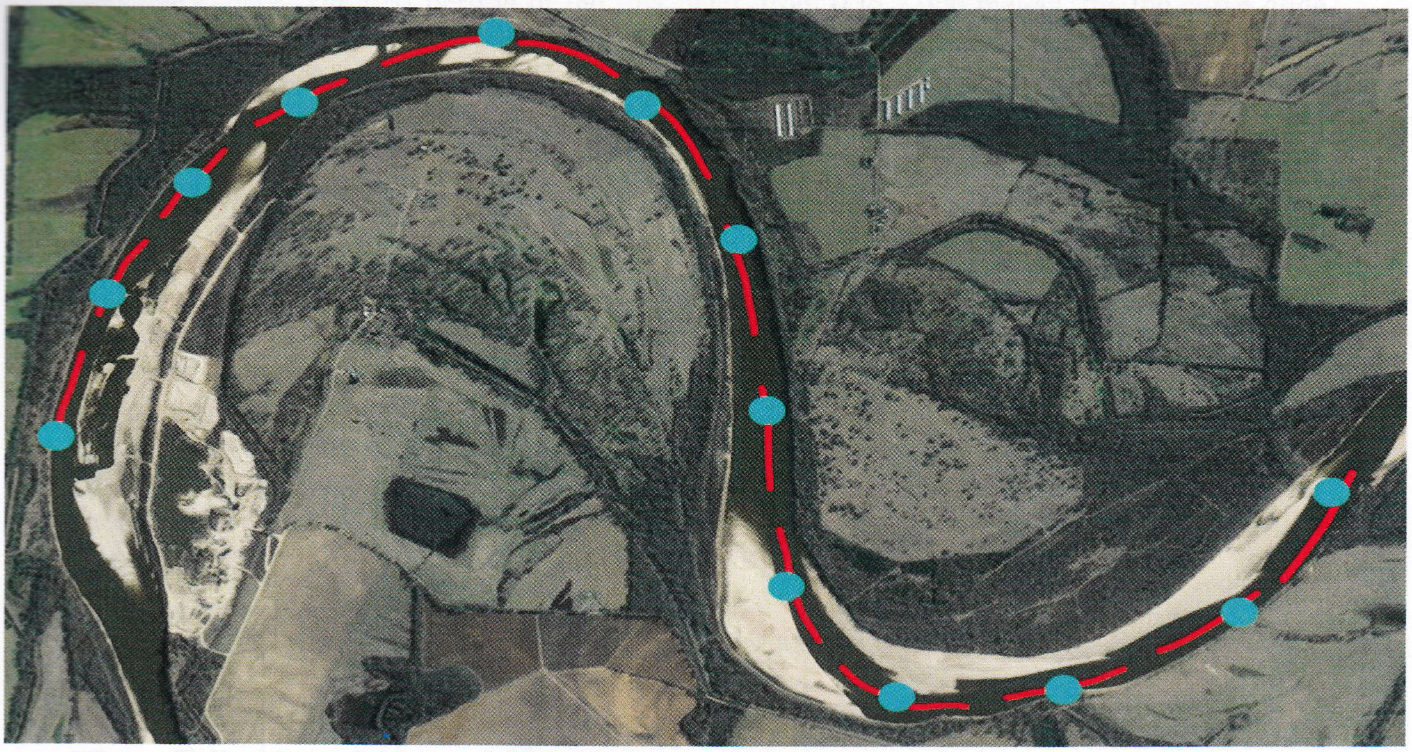


Figure 2. Google earth image of the Red River meander bend.

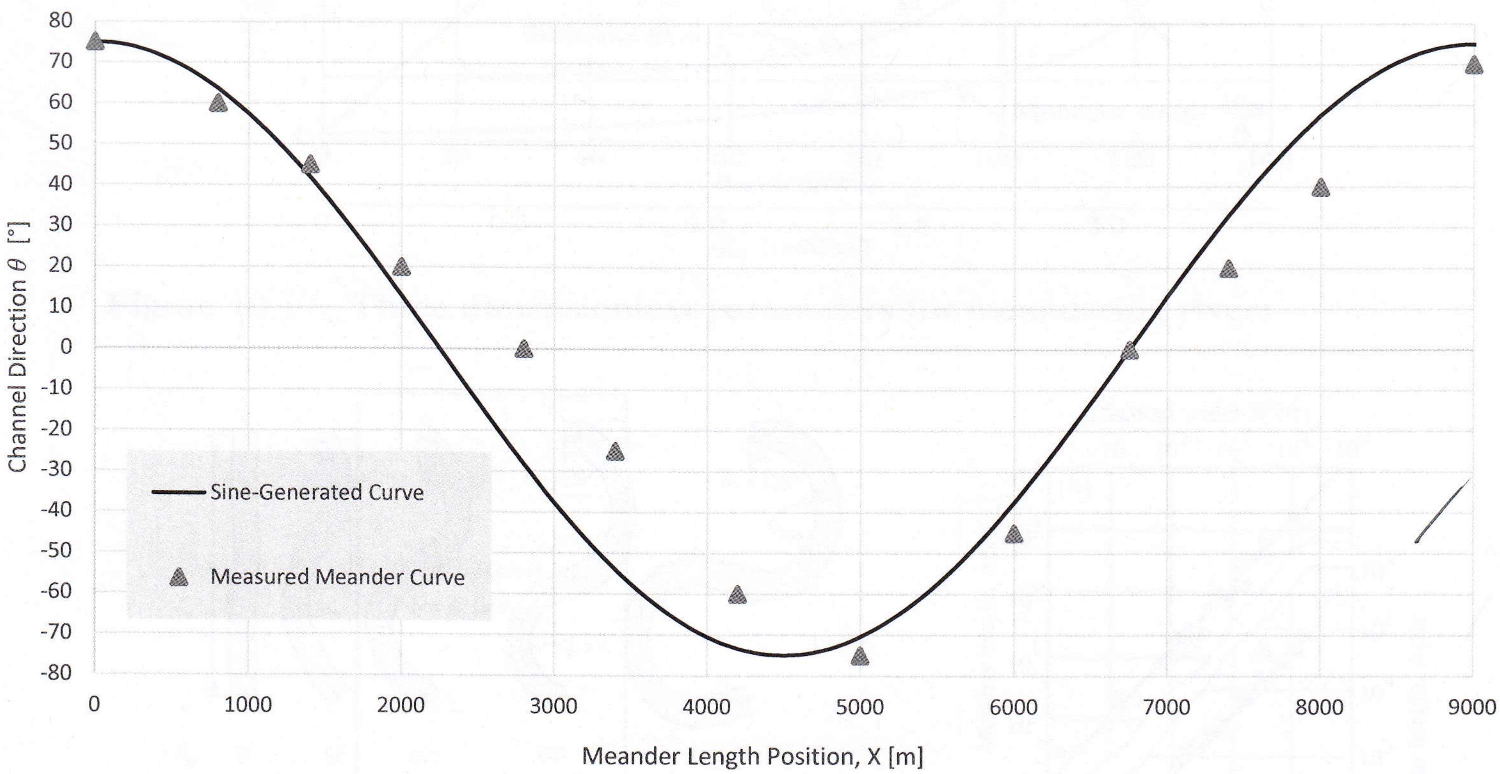


Figure 3. Sine-generated curve with measured meandering planform geometry

Discussion

Figure 3 shows a that this measured section of the Red River in Louisiana loosely follows the sine-generated curve. The first portion of the first bend, from 0 to 2,000 meters, fits the curve quite well. From 2,000 to 5,000 meters the measured curve deviates upward from the sine-generated curve, but keeps roughly the same slope. The second bend, from 5,000 to 9,000 meters, follows the sine-generate curve quite nicely, except for a slight deviation below the sign curve for the last 1,500 meters. Figures 2 and 3 align to show the physical meander locations in relation to the sin-generated curve.

Various plots from *River Mechanics (Julien 2018)* are shown below. The variables shown in Table 1 are plotted on these various plots to compare the results with published data. The variables estimated align nicely with published data shown in figure 10.17, the only outlier is the minimum radius of curvature curve for this figure. All calculated values fall in-between the 60 and 90 degree maximum deviation angle except for λ/R_{min}, this value barley falls outside of this range. The data aligns nicely to the figure shown in the bottom right, it seems that λ is greater than typical values for our given radius of curvature. These errors all seem to be a function of the radius of curvature.

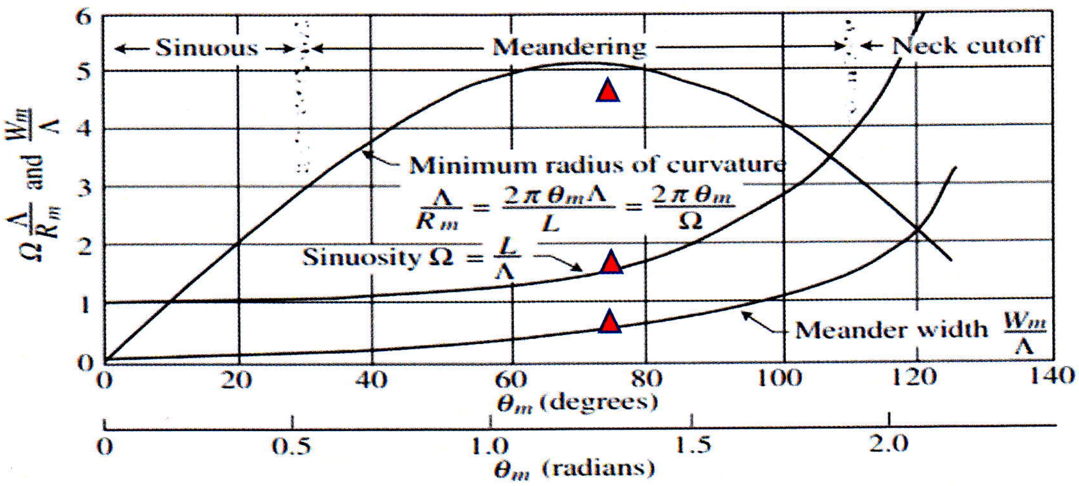


Figure 10.17. Three dimensionless parameters for meandering rivers

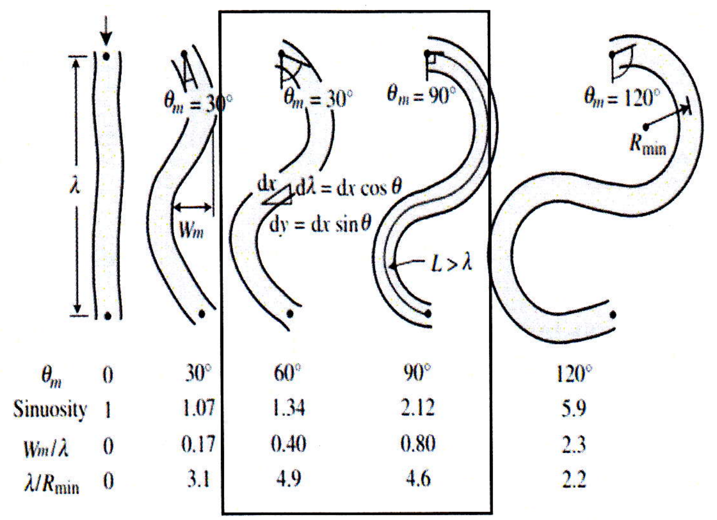
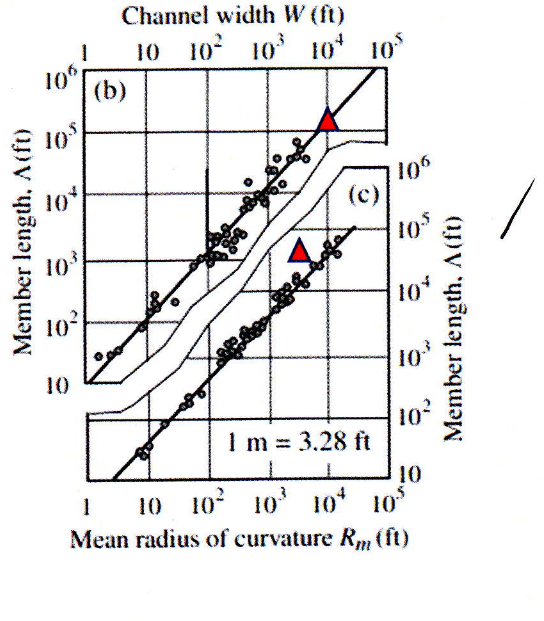


Figure 10.16. Typical meandering planform geometry



PROBLEM #4 (20%) – RIVER BRAIDING

Solve Problem 11.6 – The Jamuna River is a large, braided river with a median grain size of 0.2 mm. The river conveys ~48,000 cms at bankfull flow and the corresponding average bed-material discharge is approximately 2.6 Mtons per day. Estimate the downstream hydraulic geometry of the river.

[*Answer* – Calculate by using Equation (11.3a-e) with Q = 48,000 cms, d_s = 0.0002 m, and Q_{bv} = 11.6 cms to give h ≈ 6.7 m, W ≈ 2,500 m, V ≈ 2.8 m/s, S ≈ 3.2 x 10^{-4}, and $\tau_* \approx 6$. Field measurements in Table CS11.5.1 indicate h ≈ 6.6 m, W ≈ 4,200 m, V ≈ 1.7 m/s, S ≈ 7.5 x 10^{-5}, which gives $\tau_* \approx 15$. The calculated equilibrium slope exceeds the measured slope, and the stream is suspected to be aggrading and braiding.]

River parameters are given in the following table:

Given:		
Q	48,000	cms
d_s	0.2	mm
d_s	0.0002	m
ρ_s	2,650	kg/m³
Q_{bm}	2.6	MT/d
Q_{bv}	11.36	cms

Channel geometry was calculated using the general equation below (Equation 11.3 in the RM manual), where Y is the hydraulic parameter of interest, a is a constant, and b, c, and e are exponents for discharge, sediment size, and sediment discharge, respectively.

$$Y = aQ^b d_{50}^c Q_{bv}^e$$

Variable (Y)	a	b	c	e
h (m)	0.19	0.46	0.13	-0.12
W (m)	1.3	0.62	-0.15	-0.15
V (m/s)	4	-0.08	0.02	0.27
S (m/m)	1.2	-0.77	0.19	0.69
τ^*	0.14	-0.31	-0.67	0.57

Calculated downstream hydraulic geometry using equations 11.3(a-e) are compared with field data from CS11.5.1 below. The calculations generally under predicted width, over predicted velocity, and over predicted channel slope. This wider width, flatter slope, and corresponding velocity are indicative of a channel that is braiding and aggrading.

Downstream Hydraulic Geometry		
h	6.68	m
W	2,587	m
V	2.74	m/s
S	0.00032	m/m
τ^*	5.95	

Field Data		
h	6.6	m
W	4,200	m
V	1.7	m/s
S	0.000075	m/m
τ^*	1.5	

Problem #5 – Physical Modeling Scales, text problem #12.3

Case Study 12.1, demonstrate the model scales in Table CS12.11 are comparable to those from Table 12.1

Case Study 12.1 uses the following model characteristics tabulated in Table CS12.1.1

Table CS12.1.1. *Characteristics of the Jamuna River model (after Klaassen, 1990)*

Parameter	Prototype	Scale factor	Model
Particle size	$d_{sp} = 0.2$ mm	$d_{sr} = 1$	$d_{sm} = 0.2$ mm
Density	$G_p = 2.65$	$(G-1)_r = 1$	$G_m = 2.65$
Slope	$S_p = 7 \times 10^{-5}$	$S_r = 0.01$	$S_m = 7 \times 10^{-3}$
Discharge	$Q_p = 10{,}000\ m^3/s$ $= 90{,}000\ m^3/s$	$Q_r = 10^6$	$Q_m = 0.01\ m^3/s$ $= 0.09\ m^3/s$
Bankfull width	$W_p = 3{,}000$ m	$y_r = 1{,}000$	$W_m = 3.3$ m
Total width	15,000 m	$y_r = 1{,}000$	15 m
Flow depth	$h_p = 5.8$ m	$z_r = 200$	$h_m = 0.032$ m
Sediment transport	$q_{sp} = 1.4 \times 10^{-3}\ m^2/s$	$q_{sr} = 80$	$q_{sm} = 1.34 \times 10^{-5}\ m^2/s$
Flood duration	$T_p = 78$ days	$t_r = 2{,}500$	$T_m = 0.03$ day
Froude number	$Fr_p = 0.1–0.2$	$Fr_r = 0.25$	$Fr_m = 0.4–0.8$

Applying the given model scales to the scale ratios in Table 12.1, using $d_{sr}=1$ & m=0.09, we find the following:

Parameter	Equations	Calculated Value	Table CS12.1.1 Value
t_r	$t_r = x_r^{1-0.5m}$	$t_r=6600$	$t_r=2500$
Q_r	$Q_r = y_r x_r^{0.5+0.5m}$	$Q_r=1.5*10^6$	$Q_r=1.0*10^6$
S	$S_r = x_r^{-0.5}$	S=0.01	S=0.01
Fr	$Fr = x_r^{0.5m-0.25}$	Fr=.15	Fr=.25

The scales of time, and Froude # show substantial differences. The case study indicates that the Froude similitude could not be attained for the model, so this is not greatly important.