Uniform Channel Flow – Basic Concepts

Hydromechanics VVR090

Definition of Uniform Flow

Uniform occurs when:

1. **The depth, flow area, and velocity at every cross section is constant**
2. **The energy grade line, water surface, and channel bottom are all parallel:**

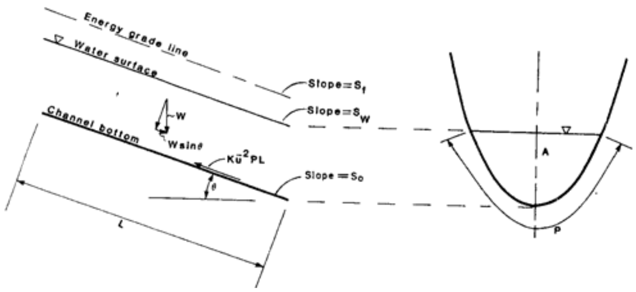
$$S_f = S_w = S_o$$

S_f = slope of energy grade line

S_w = slope of water surface

S_o = slope of channel bed

Definition Sketch for Uniform Flow



Conditions that allow uniform flow to develop rarely satisfied in practice. However, concept of great significance in understanding and solving most problems in open-channel hydraulics.

Uniform flow occurs in lomg, straight, prismatic channel where a terminal velocity can be achieved.

=> Balance between head loss due to turbulent flow and reduction in potential energy

(Balance between gravity and boundary shear forces)

Momentum Equation for Uniform Flow I

Gravity force (causing motion):

$$F_m = W \sin\theta = \gamma A L \sin\theta$$

Boundary shear force (resisting motion):

$$F_R = \tau_o L P$$

Shear stress proportional to bottom velocity squared:

$$\tau_o = k\bar{u}^2$$

Momentum Equation for Uniform Flow II

Steady state conditions: gravity force = shear forces

$$F_m = F_R$$

$$\gamma A L \sin\theta = k\bar{u}^2 L P$$

$$\bar{u} = \left(\frac{\gamma}{k}\right)^{1/2} \sqrt{RS}$$

$$R = \frac{A}{P}$$

The Chezy Equation

The Chezy equation is given by:

$$\bar{u} = C\sqrt{RS}$$

$$C = \left(\frac{\gamma}{k}\right)^{1/2}$$

C has the dimensions L/T^2

The Manning Equation

The Manning equation is given by:

$$\bar{u} = \frac{1}{n}R^{2/3}\sqrt{S}$$

n has the dimensions $T/L^{-1/3}$

Compare with the Chezy equation:

$$C = \frac{R^{1/6}}{n}$$

General Equation for Uniform Flow

Most semi-empirical equation for the average velocity of a uniform flow may be written:

$$\bar{u} = CR^x S^y$$

Manning equation most commonly employed equation in open channel flow (*x*=2/3, *y*=1/2).

Will be used for calculations in the present course.

Flow Resistance Coefficients I

Difficult to estimate an appropriate value on the resistance coefficient in the Manning or Chezy equations.

Should depend on:

- **Reynolds number**
- **boundary roughness**
- **shape of channel cross section**

Compare with the Darcy-Weisbach formula for pipe friction:

$$h_L = f \frac{L}{4R} \frac{\bar{u}^2}{2g}$$

Flow Resistance Coefficients II

Slope of the energy line:

$$S = \frac{h_L}{L} = \frac{f}{4R}\frac{\overline{u}^2}{2g}$$

Compare with Manning and Chezy equation:

$$n = R^{1/6}\sqrt{\frac{f}{8g}}$$

$$C = \sqrt{\frac{8g}{f}}$$

Types of Turbulent Flow

Two main types of turbulent flow:

• hydraulically smooth turbulent flow

Roughness elements covered by viscous sublayer (resistance depends on Reynolds number *Re*)

• hydraulically rough flow

Roughness elements penetrates through the viscous sublayer (resistance coefficient depends on roughness height k_s)

Transitional region in between these flows (dependence on *Re* and k_s)

Example of Roughness Heights (k_s)

TABLE 4.1 Values of k_s for various types of concrete and masonry surfaces (Ackers, 1958, and Zegzhda, 1938, both in Anonymous, 1963b)

k_s	Surface description
0.0005	Concrete class 4 (monolithic construction, cast against oiled steel forms with no surface irregularities)
0.001	Very smooth cement-plastered surfaces, all joints and seams hand-finished flush with surface
0.0016	Concrete cast in lubricated steel molds, with carefully smoothed or pointed seams and joints
0.002	Wood-stave pipes, planed-wood flumes, and concrete class 3 (cast against steel forms, or spun-precast pipe); smooth troweled surfaces; glazed sewer pipe
0.005	Concrete class 2 (monolithic construction against rough forms or smooth-finished cement-gun surface, the latter often termed *gunite* or *shot concrete*); glazed brickwork
0.008	Short lengths of concrete pipe of small diameter without special facing of butt joints
0.01	Concrete class 1 (precast pipes with mortar squeeze at the joints); straight, uniform earth channels
0.014	Roughly made concrete conduits
0.02	Rubble masonry
0.01–0.03	Untreated gunite

Definition of Reynolds Number

Definitions of Reynolds number:

$$\mathrm{Re} = \frac{\overline{u}\,4R}{\nu}$$

$$\mathrm{Re}_* = \frac{u_* k_s}{\nu}$$

$$u_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{gRS}$$

Criteria for Turbulent Flow Types

$0 \le \mathrm{Re}_* \le 4$ smooth

$4 \le \mathrm{Re}_* \le 100$ transition

$100 \le \mathrm{Re}_*$ rough

Pipe Flow Friction Factors

Hydraulically smooth flow:

$$f = \frac{0.316}{\mathrm{Re}^{0.25}} \qquad \mathrm{Re} < 100{,}000$$

$$\frac{1}{\sqrt{f}} = 2.0 \log\left(\frac{\mathrm{Re}\sqrt{f}}{2.51}\right) \qquad \mathrm{Re} > 100{,}000$$

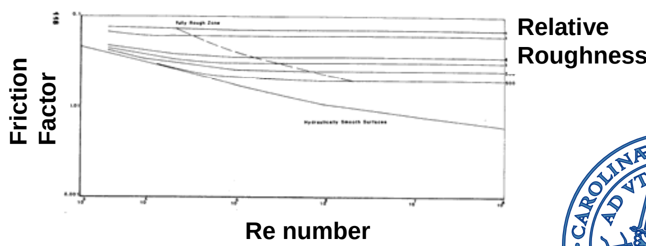
Hydraulically rough flow:

$$\frac{1}{\sqrt{f}} = 2.0 \log\left(\frac{12R}{k_s}\right)$$

Colebrook's formula applicable for the transition region:

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{k_s}{12R} + \frac{2.5}{\mathrm{Re}\sqrt{f}}\right)$$

Plots of f versus $k_s/4R$ and *Re* (analogous to a Moody diagram).



Selecting a Manning's roughness

Difficult to apply *f* from pipe flow.

⇒ Manning's *n* is often determined based on emprical knowledge, including the main factors governing the flow resistance:

- surface roughness
- vegetation
- channel irregularity
- obstruction
- channel alignment
- sedimentation and scouring
- stage and discharge

Soil Conservation Service (SCS) Method for *n*

Determine a basic n for a uniform, straight, and regular channel, then modify this value by adding correction factors.

Each factor is considered and evaluated independently.

Channel Characteristics	Basic n
In earth	0.020
Cut in rock	0.025
In fine gravel	0.024
In coarse gravel	0.028

Procedure:

1. **Select basic n**
2. **Modify for vegetation**
3. **Modify for channel irregularity**
4. **Modify for obstruction**
5. **Modify for channel alignment**
6. **Estimate *n* from step 1 to 5**

A total *n* is obtained as the sum of the different contributions.

Influence of Vegetation

TABLE 4.3 Modifying factors for vegetation (Anonymous, 1963b)

Vegetation and flow conditions comparable with:	Degree of effect on n	Range of modifying values
Dense growths of flexible turf grasses or weeds, of which Bermuda grass and blue grass are examples, where the average depth of flow is 2 to 3 times the height of vegetation Supple seedling tree switches such as willow, cottonwood, or salt cedar where the average depth of flow is 3 to 4 times the height of the vegetation	Low	0.005–0.010
Turf grasses where the average depth of flow is 1 to 2 times the height of vegetation Stemmy grasses, weeds, or tree seedlings with moderate cover where the average depth of flow is 2 to 3 times the height of vegetation Brushy growths, moderately dense, similar to willows 1 to 2 years old, dormant season, along side slopes of channel with no significant vegetation along the channel bottom, where the hydraulic radius is greater than 2 ft (0.6 m)	Medium	0.010–0.025
Dormant season, willow or cottonwood trees 8 to 10 years old, intergrown with some weeds and brush, none of the vegetation in foliage, where the hydraulic radius is greater than 2 ft (0.6 m) Growing season, bushy willows about 1-year-old intergrown with some weeds in full foliage along side slopes, no significant vegetation along channel bottom, where hydraulic radius is greater than 2 ft (0.6 m)	High	0.025–0.050
Turf grasses where the average depth of flow is less than one-half the height of vegetation Growing season, bushy willows about 1 year old, intergrown with weeds in full foliage along side slopes; dense growth of cattails along channel bottom; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6 m) Growing season, trees intergrown with weeds and brush, all in full foliage; any value of hydraulic radius up to 10 or 15 ft (3 to 4.6 m)	Very high	0.050–0.100

Influence of Cross-Section Size and Shape, and Irregulariy

TABLE 4.4 Modifying factors for changes in cross-section size and shape (Anonymous, 1963b)

Character of variations in size and shape of cross sections	Modifying value
Changes in size or shape occurring gradually	0.000
Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side	0.005
Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side	0.010–0.015

TABLE 4.5 Modifying factors for channel surface irregularity (Anonymous, 1963b)

Degree of irregularity	Surfaces comparable with	Modifying value
Smooth	The best obtainable for the materials involved	0.000
Minor	Good dredged channels; slightly eroded or scoured side slopes of canals or drainage channels	0.005
Moderate	Fair to poor dredged channels; moderately sloughed or eroded side slopes of canals or drainage channels	0.010
Severe	Badly sloughed banks of natural channels; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels excavated in rock	0.020

Influence of Obstruction and Channel Alignment

TABLE 4.6 Modifying factors for obstruction (Anonymous, 1963b)

Relative effect of obstructions	Modifying value
Negligible	0.000
Minor	0.010–0.015
Appreciable	0.020–0.030
Severe	0.040–0.060

TABLE 4.7 Modifying values for channel alignment (Anonymous, 1963b)

ℓ_m / ℓ_s	Degree of meandering	Modifying value
1.0–1.2	Minor	0.00
1.2–1.5	Appreciable	0.15 n'
>1.5	Severe	0.30 n'

TABLE 4.8 Values of the roughness of coefficient *n* (Chow, 1959)

Type of channel and description	Minimum	Normal	Maximum
A. Closed conduits flowing partly full			
A-1. Metal			
a. Brass, smooth	0.009	0.010	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
A-2. Nonmetal			
a. Lucite	0.008	0.009	0.010
b. Glass	0.009	0.010	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer and manholes, inlet, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminated, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	0.013	0.017

Example of Manning's *n* from Chow (1959)

(illustrative pictures in the following)

Manning's Roughness *n*

(1)

0.012

(2)

0.014

(3)

0.016

(4)

0.018

(5)

0.018

(6)

0.020

Manning's Roughness *n*

(7)

0.020

(8)

0.022

(9)

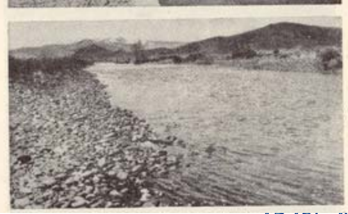
0.024

(10)

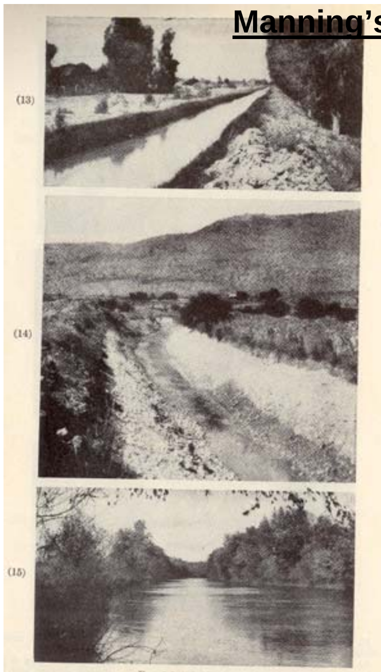
0.024

(11)

0.026

(12)

0.028

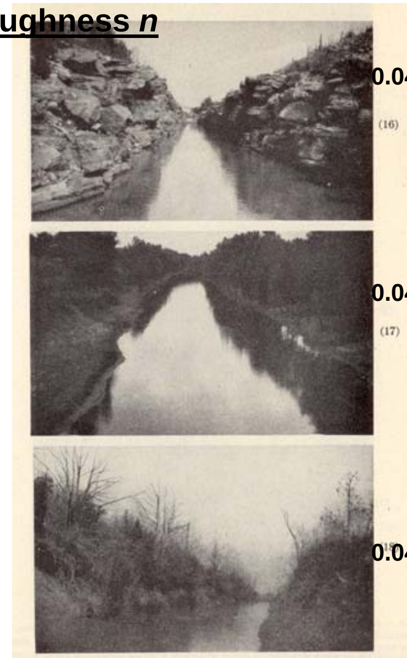
Manning's Roughness *n*



0.029

0.030

0.035

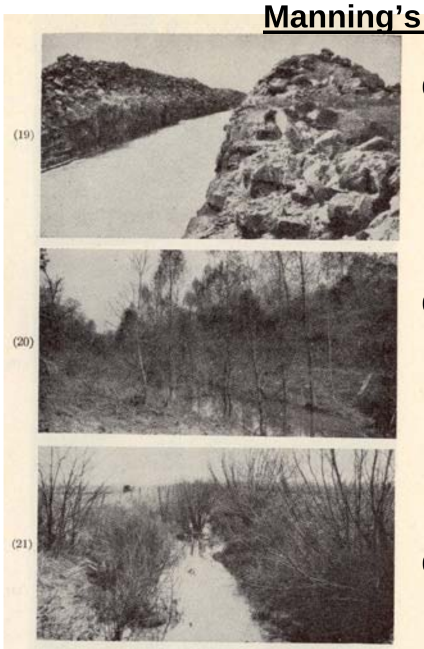


0.040

0.040

0.045

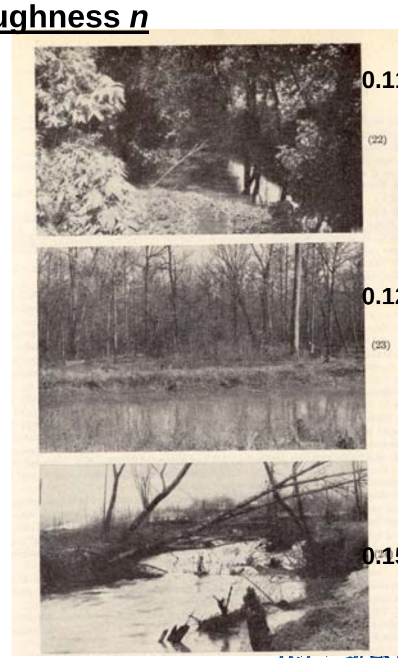
Manning's Roughness *n*



0.050

0.060

0.080



0.110

0.125

0.150