INVESTIGATION OF EFFECT OF SPACING BETWEEN LATERAL SQUARE BARS ON CHANNEL BED RESISTANCE

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ABSTRACT

INVESTIGATION OF EFFECT OF SPACING BETWEEN LATERAL SQUARE BARS ON CHANNEL BED RESISTANCE

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Irregularities of solid surfaces affect the friction between the surface and the flowing fluid. Surface irregularities are generally defined as 'roughness', which implies an increase in bed resistance and additional dissipation from flow energy. Thus, surface finishing is critical in many engineering applications to minimize energy losses. However, there are specially designed hydraulic structures where the purpose is to dissipate the flow energy. A typical application is to place large-scale obstructions on the bed as macro roughness elements so that more flow energy is dissipated by increased bed resistance. This study aims to investigate the effect of spacing between square cross-sectioned bars fixed laterally on the bed of a prismatic laboratory channel on energy dissipation using experimental methods. Different rib spacings, in other words, pitch distances (p=32, 16, 8, 4, 2 cm) have been analysed, and it is found that up to a limit (p/k=16, where k is the square rib dimensions) when rib spacing decreases, bed resistance increases. However, after the limit, decreasing the spacing does not increase the bed resistance but decreases it.

Keywords: Bed roughness, Friction factor, Open channel flow, Rib roughness, Uniform flow

ÖZ

ENİNE KARE ÇUBUKLAR ARASINDAKİ BOŞLUĞUN KANAL YATAĞI DİRENCİ ÜZERİNDEKİ ETKİSİNİN İNCELENMESİ

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Katı yüzeylerin düzensizliği, yüzey ve akışkan arasındaki sürtünme oluşumunu etkiler. Yüzey düzensizlikleri genellikle kanal tabanındaki sürtünmede artış ve akışkanın enerjisindeki ek kayıp anlamına gelen "pürüzlülük" olarak tanımlanır. Bu yüzden, yüzey parlaklığı birçok mühendislik uygulamasında enerji kaybını azaltmak için önemli bir konudur. Ancak, özel olarak tasarlanmış, amacı akım enerjisini azaltmak olan hidrolik yapılar da vardır. Kanal tabanına büyük ölçekli yapıları makro pürüzlülük elemanı olarak yerleştirmek yaygın bir uygulamadır. Böylece kanal tabanındaki sürtünmenin artışıyla akışkanın enerjisi daha fazla azaltılır. Bu çalışmanın amacı kanal tabanına enine sabitlenmiş kare enkesitli çubukların arasındaki mesafenin enerji kaybına olan etkisini deneysel yöntemler kullanarak incelemektir. Farklı çubuk aralıkları (p=32, 16, 8, 4, 2 cm) incelenmiş ve bir sınıra kadar (p/k=16, k çubuk boyutu), çubuk aralığı azaldıkça taban sürtünmesinin arttığı görülmüştür. Ancak bu limitten sonra aralığın azalması taban sürtünmesini arttırmaz, aksine azaltır.

Anahtar Kelimeler: Yatak pürüzlülüğü, Sürtünme katsayısı, Açık kanal hidroliği, Çubuk pürüzlülüğü, Üniform akım

To My Beloved Family

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A	Area, m^2
b	Channel Width, m
D_h	Hydraulic Depth, m
f	Friction Factor
F	Friction Force, N
F_H	Hydrostatic Force, N
Fr	Froude Number
k	Rib Height, m
k_s	Surface Roughness, m
L	Length of Control Volume, m
m	Correction Factor for Manning's n
n	Manning's Coefficient
P	Perimeter, m
p	Pitch Distance, m
Q	Discharge, m^3/s
R_h	Hydraulic Radius, m
R1, 2, 3, 4, 5	Roughness Pattern Name
Re	Reynolds Number
S	Slope
s	Rib Spacing (Distance Between Ribs), m
u^*	Friction Velocity or Shear Velocity, m/s
V	Average Velocity, m/s
W	Weight, N
w	Rib Spacing (Distance Between Ribs), m
y_a	Actual Flow Depth, m
y_n	Uniform Flow Depth, m
z_a	Flow Depth from Datum, m
ρ	Density, kg/m^3
τ	Wall Shear Stress, Pa
θ	Channel Angle, Degree
γ_w	Specific Weight of Water, kN/m^3

CHAPTER 1

INTRODUCTION

1.1 Overview of Uniform Flow

Open channels are waterways, canals, or conduits where liquids flow with a free surface. In other words, liquid flows under constant atmospheric pressure in a canal. The driving force in open channels is mainly the gravity caused by the slope of the channel. The hydraulic properties of the open channel are affected by the properties of fluids i.e., density, viscosity, the geometry of the channel i.e., shape, slope, and flow properties i.e., depth, velocity.

Open channel flow can be classified as different types in various ways or criteria. For example, one can use time as the criterion. If flow depth does not vary with time, it is called *steady flow*. If it changes with time, it is called *unsteady flow*.

Also, *space* can be used as the criterion. If the flow depth is identical at every channel section, it is called *uniform flow*. If flow depth changes over the length of the channel, it is called *varied flow*. Uniform flow can be steady or unsteady depending on whether the depth changes with time.

Steady uniform flow is a fundamental type of flow studied in open-channel hydraulics.

Also, one can use Froude and Reynolds Number to classify open channel flow (Graf & Altınakar, 1998). The following section will summarize the hydraulics of uniform flow in open channels.

1.2 Uniform Flow Equations

Basic equations and principles used in uniform open channel flow will be summarized in this section.

Firstly, the momentum equation in the flow direction, represented in Fig. 1.1, will be discussed.

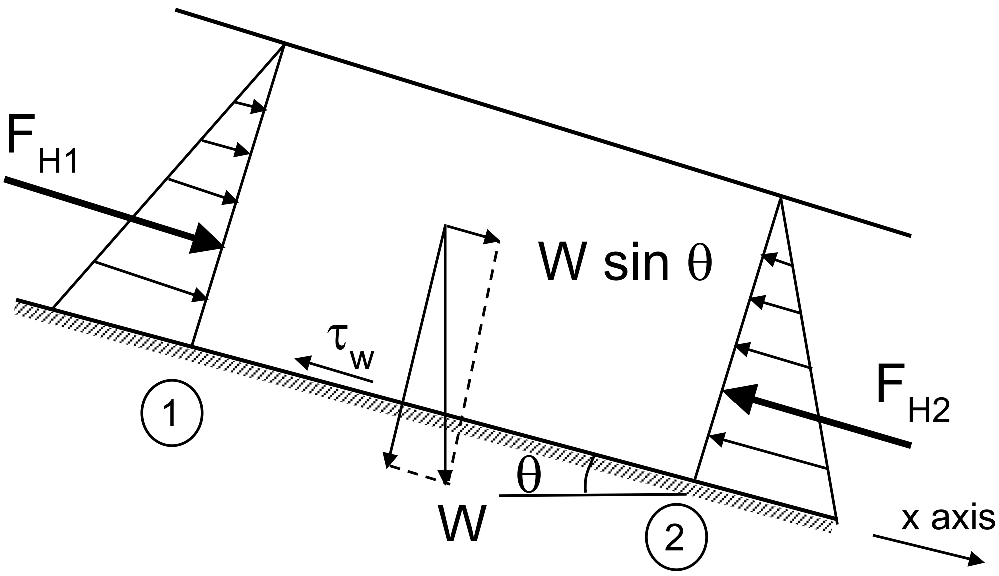

Figure 1.1 Momentum Equation in Flow Direction

In Fig. 1.1, F_{H1} and F_{H2} represent hydrostatic forces in sections 1 and 2, respectively. W represents the water weight in the control volume, $W=\gamma_w AL$, and τ_w represents wall shear stress. Since water depths are equal, these forces are equal. Also, the velocity in section 1 and section 2 are equal. Moreover, $\sin\theta$ is almost equal to the channel bottom slope, S_0. Then equation can be written:

$$F_{H1} - F_{H2} - \tau_w PL + W\sin\theta = \rho Q(V_2 - V_1) \tag{1}$$

In this equation, P represents the wetted perimeter, L represents the length of control volume, ρ is the density of water, Q is discharge, V_1 and V_2 represent velocities in section 1 and 2, respectively.

$$\tau_w PL = \gamma_w ALS_0 \tag{2}$$

As a result, an essential relation for wall shear stress can be found:

$$\tau_w = \gamma_w R_h S_0 \tag{3}$$

In this equation, γ_w represents the specific weight of water, R_h represents the hydraulic radius.

There is an important relation between the wall shear stress and Darcy Friction Factor defined in Eq. (4):

$$f = \frac{8\tau_w}{\rho V^2} \tag{4}$$

In this equation, f represents Darcy Friction Factor, τ_w represents wall shear stress.

The pressure drop or head loss in a pipe or channel caused by frictional effects is calculated using the Darcy friction factor, a crucial fluid mechanics metric.

The Darcy friction factor is significant because it is a crucial part of the Darcy-Weisbach equation. It links the flow rate, pipe diameter, and fluid characteristics like density and viscosity to the pressure drop or hydraulic loss in a pipe or channel. Engineers can precisely anticipate the pressure drop or hydraulic loss in a pipe or channel and construct fluid systems by the Darcy-Weisbach equation and the Darcy friction factor. Because it is influenced by the flow's Reynolds number and the roughness of the pipe or channel surface, the Darcy friction factor is also significant. As a result, it can be used to compare the performance of various pipes or channels with various levels of surface abrasion and flow regimes.

The Darcy friction factor, in general, is a fundamental fluid mechanics parameter crucial for planning and analysing fluid systems and forecasting the behaviour of fluids through pipes and channels.

Manning's Equation: This empirical equation can be applied to uniform flow in open channels. It is especially used in river flow.

$$V = \frac{1}{n} R_h^{\frac{2}{3}} \sqrt{S_0} \tag{5}$$

In this equation, n is Manning's coefficient. Manning's n is dependent on material type, section geometry, channel alignment, channel size and turbulence. Recommended values for different surface materials are shown in Table 1.1.

Table 1.1 Manning's n Coefficients (Chow, 1959)

Material Type	Manning's n Coefficient
Steel, painted smooth surface	0.013
Metal, corrugated	0.025
Concrete, on good, excavated rock	0.020
Concrete, unfinished	0.017
Wood, planed, creosoted	0.012
Brick, glazed	0.013
Masonry, cemented rubble	0.025
Asphalt, smooth	0.013
Asphalt, rough	0.016
Glass	0.010

A detailed description of n can be made by defining a parameter for different aspects of flow and channel (De Doncker et al, 2009).

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m \quad (6)$$

In this equation, n_0 is a fundamental value for a straight uniform channel, n_1 is irregularities of the channel bottom, n_2 is variations in the geometry of the channel, n_3 represents obstacles, n_4 represents vegetation, and m is the correction factor.

Manning's equation is the most widely used in open-channel hydraulics among researchers and hydraulics engineers in practice, (Chezy's Equation has fewer practical samples). The reasons can be listed below:

- It is easy to use.
- It is proven by practical experience.
- It is accurate because Manning's n values are selected from field measurements.

1.3 Problem Description

Determining bed resistance in channel flow is crucial in many engineering problems. Solid surfaces' irregularities affect the friction between the surface and the flowing fluid. Surface irregularities are generally defined as 'roughness', which implies an increase in bed resistance and additional dissipation from the flow energy. Thus, surface finishing is critical in many engineering applications to minimize energy losses.

However, there are specially designed hydraulic structures where the purpose is to dissipate the flow energy i.e., flip buckets, baffle blocks, end sills. A typical application is to place large-scale obstructions on the bed as macro roughness elements so that more flow energy is dissipated by increased bed resistance.

This study experimentally investigates the roughness effect of lateral rib elements on the channel bed. Rib spacing is the essential variable of the study, in addition to channel slope and discharge. Rib roughness is formulated in terms of Manning's parameter, n, and Nikuradse's equivalent sand roughness, k_s.

CHAPTER 2

LITERATURE REVIEW

In this section, both numerical and experimental studies found in the related literature will be summarized. Cui, Patel, & Lin (2003) used Large Eddy Simulation or (LES) to investigate turbulent flow in a channel with rib roughness. Different rib configurations have been studied to understand the behaviour of rib roughness. In this study, three different patterns of ribs were studied, which were s/k=1,4,9, where s was the distance between two consecutive ribs and k was roughness height. Streamlines for three types of roughness were examined. For s/k=1, streamlines above the rib height were almost parallel. A vortex fills the cavity between the two consecutive ribs. For s/k=4, streamlines above the cavity are nearly parallel except near the rib. For s/k=9, streamlines for this roughness pattern reveal four separation zones associated with the consecutive ribs. Due to these different vortices occurring in grooves, their drag force was different from each other. Of the three roughness types, s/k=9 roughness has the highest drag, almost four times that of s/k=1 roughness.

Leonardi, Orlandi, Smalley, Djenidi, & Antonia (2003) conducted direct numerical simulations for a fully developed turbulent flow with square bars on the channel bottom. Several rib configurations have been studied. These were w/k=0.33, 0.6, 1, 2.07, 3, 4, 5.5, 7, 8, 9, 10, where w was the distance between two consecutive ribs.

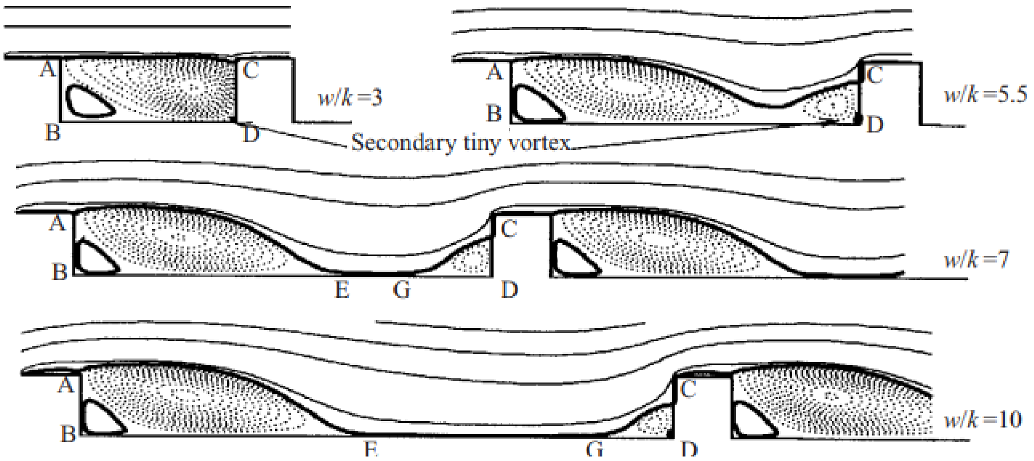

Figure 2.1 Mean Streamlines for Different Configurations (Leonardi, Orlandi, Smalley, Djenidi, & Antonia, 2003)

In all the simulations, the flow rates have been kept constant. The effect of s/k on the overall behaviour of the flow between roughness elements were investigated. For w/k≤4, separation occurs at the hindermost edge of the element. Also, reattachment is on the opposite vertical wall. The cavity has a significant recirculation region occupied by two secondary vortices that circulate in the opposite direction to the primary recirculation zone. For w/k≥7, the flow reattaches on the bottom wall. The near-wall streamlines are almost horizontal between the separation zones. As the next element is reached, the streamlines are inclined upward, and separation occurs. It can be seen from the Fig. 2.1, when w/k exceeds a critical value which is w/k=7, the flow remains unchanged around the roughness elements. The roughness elements become isolated when w/k>7, which means that the strength and size of the primary recirculation zone are no longer influenced by the size of the roughness components. Maximum drag occurs at w/k=7 when the reattachment on the bottom occurs immediately upstream of the following element.

Ashrafian, Andersson, & Manhart (2004) performed a numerical investigation to study pressure-driven turbulent flow in a rod-roughened by square rods. The pitch-to-height ratio was 8. Vortices which filled the cavity were observed between two consecutive rods.

The averaged flow field that detached from one rod did not reattach, and a return flow was recorded all the way along the cavity's bottom. There was no noticeable streamwise fluctuation of the mean velocity or second-order statistics outside the roughness sublayer.

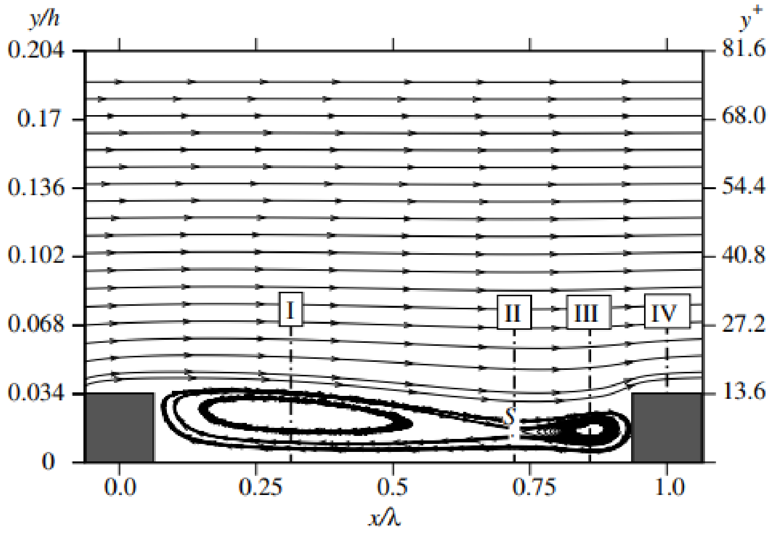

Figure 2.2 Streamline Pattern Near the Roughness Elements (Ashrafian, Andersson, & Manhart, 2004)

The mean flow separates from the roughness elements and creates a separation bubble downstream of each rod, while just upstream of the next rod, a smaller vortex with the same sign of circulation forms. The mean flow never attaches at the cavity's bottom, but instead creates a saddle point (S) between the two recirculation zones.

Agelinchaab & Tachie (2006) conducted an experimental study. Unlike traditional research, which uses two-dimensional transverse ribs, researchers used hemispherical ribs as an artificial roughness. The pitch-to-height ratio was defined from centre-to-centre distance over a hemisphere radius. Researchers used three different ratios: p/k=2,4,8. Streamlines, mean velocity, and time-averaged turbulent statistics were used to understand the behaviour of the pitch-to-height ratio. It was observed that interaction between outer flow and shear layers generated by ribs was strongest for p/k=8 and least for p/k=2 ribs. The results also showed that hemispherical ribs were less effective in augmenting flow resistance compared to two-dimensional transverse ribs.

Tachie, Agelinchaab & Shah (2007) conducted an experimental study. This study was an experimental study of favourable pressure gradient turbulent flow over transverse square ribs in an open channel. Researchers used pitch-to-height ratios of 2,4, and 8. Also, particle image velocimetry was used in order to conduct velocity measurements. The study found that the interaction between the overlying boundary layer and p/k=2 cavities had little effect on the flow over p/k=2 rib, resulting in a drag coefficient comparable to or only slightly higher than that of a smooth wall. However, in the case of p/k=8 roughness cavities, there was a significant interaction with the overlying boundary layer, leading to a high mean momentum flux along the interface that exceeded the Reynolds shear stress at some locations. As a result, the turbulence levels over p/k=8 ribs were much higher than those over p/k=2 ribs, with increased turbulent intensities, Reynolds shear stress, and turbulence production as the pitch ratio increased.

Dritselis (2014) conducted numerical study. The researcher used different roughness elements and configurations and analysed them using Large Eddy Simulation Method. Pitch-to-height ratios for square transverse ribs were s/k=1,3,7. The researcher defined s as the distance between one rib end and one rib face. It can be understood that it was similar to other research because their pitch distance was defined as p as the distance from the two successive rib ends. As can be understood from the conclusions, for s/k = 1, the whole cavity was occupied by a single recirculation region. The size of the vortex was increased for s/k = 3, and a smaller secondary vortex with opposite circulation was observed close to the left vertical wall of the cavity. For these two cases of s/k = 1 and 3, the separation of the flow occurred at the edge of each element, while the flow was reattached at the vertical wall of the following roughness element. For s/k = 7, a large recirculation zone was located downstream of each element, accompanied by a smaller vortex. The flow was reattached to the bottom wall of the cavity and separated again as the vertical wall of the next element was approached. The present Large Eddy Simulation results were in good qualitative agreement with the results of Cui et al. (2003), who used a body-fitted numerical code coupled with Large Eddy Simulation in order to study the turbulent flow in similar geometries.

Nadeem, Lee, Lee & Sung (2015) conducted a numerical investigation to study turbulent boundary layers over two-dimensional rod-roughened walls. The study involved the periodic arrangement of rod elements with varying pitches of p/k = 8, 16, 32, 64 and 128, where p is the streamwise spacing of the rods and k is the roughness height. The results showed that for the sparsely distributed rough walls with p/k≥32, the outer-layer similarity between the rough and smooth walls was established based on the profiles of the Reynolds stresses. However, this was not the case for p/k = 8 and 16, where the interaction between outer-layer large-scale motions and near-wall small-scale motions was strongly disturbed over the rough wall. For p/k≥32, the flow that passed through the upstream roughness element transitioned to a smooth wall flow between the consecutive rods. The study revealed that the form drag, friction velocity, and roughness function for flows over the rough walls strongly depended on p/k, with maximum and minimum values occurring at p/k = 8 and 128, respectively. The authors attributed the strong influence of surface roughness in the outer layer for p/k = 8 and 16 to large-scale erupting motions caused by the surface roughness, resulting in an upward shift of near-wall turbulent energy and active energy production in the outer layer with little impact on the near-wall region.

Okazaki, Takase, Kuwata & Suga (2022) conducted experimental study. Particle Image Velocimetry measurements of turbulent channel flow over porous roughness are carried out to understand permeable roughness effects on turbulence. They considered fully developed turbulent channel flows over porous bottom walls with transverse square porous ribs whose heights are 10% of the channel height. The ratios of the rib spacing w to the rib height k were w/k =1, 3, 7, 9 and 19. At w/k = 1, the turbulence quantities and drag coefficient levels become more extensive as the permeability increases, while such a trend becomes unclear at w/k = 3, and a reversed trend is seen at w/k ≥ 7. At a higher permeability, however, it is found that the sensitivity to the rib spacing on the profiles of the turbulence quantities and the drag coefficient is weakened. Even at a lower permeability, turbulence tends to be less sensitive to the rib spacing at w/k > 3.

Cheng & Chua (2005) conducted a study which provides a quantitative assessment of the existing correction procedures by comparing them. The measurement of bed shear stress using bulk flow characteristics in laboratory open-channel flows is frequently affected by sidewall friction effects. The method for removing sidewall effects is known as sidewall correction. As a result of the comparisons, the Einstein correction formula and the Vanoni and Brooks method generally predict relatively lower and higher bed shear stresses, respectively, while the Williams' empirical function leads to more scatter. Thus, first two correction methods will be used later in this thesis study to compare them with the current method.

Einstein (1942) Formula

Einstein used the Manning roughness coefficient to distinguish flow resistance components associated with the bed and the wall.

$$\frac{\tau_{bed}}{\rho g h S} = 1 - \frac{2 n_w^{1.5} V^{1.5}}{b S^{0.75}} \tag{7}$$

In this equation, τ_{bed} is average bed shear stress, b is channel width, h is flow depth, n_w is wall-related roughness coefficient, which is smooth glass walls, n_{glass}=0.009 (Daughtery et al. 1989) for this thesis study. In Eq. (7), replacing n_w with 0.009, equation can be written as Eq. (8):

$$\frac{\tau_{bed}}{\rho g h S} = 1 - 0.0017 \frac{V^{1.5}}{b S^{0.75}} \tag{8}$$

Vanoni and Brooks (1957) Formula

Vanoni and Brooks expressed the bed shear stress using the friction factor as shown in Eq. (9).

$$\frac{\tau_{bed}}{\rho g h S} = \frac{\mathrm{b}}{\mathrm{b} + 2\mathrm{h}} \frac{f_b}{f} \tag{9}$$

In this equation, $f_b = f + 2h(f - f_w)/b$ is the bed friction factor and f_w is wall friction factor which has own relations.

Moreover, when the wall friction is described using Darcy-Weisbach friction factor instead of Manning coefficient, Eq. (7) can be expressed as Eq. (10) using related estimations given by Cheng & Chua (2005).

$$\frac{\tau_{bed}}{\rho g h S} = 1 - 0.0012\frac{V^{1.4}}{bS^{0.8}} \tag{10}$$

As mentioned before, these correction methods (Eq. (8), Eq. (9) and Eq. (10)) will be compared with the correction used in this study.

Chow, V. T. (1959) summaries flow over rough surfaces could be classified into three basic types: *isolated-roughness flow*, *wake-interference flow*, and *quasi-smooth (skimming) flow*.

When roughness elements are placed far away from each other, isolated-roughness flow occurs. The wake and vortex at each element are entirely developed and dissipated before the next element is reached. The pitch-to-height ratio might be a significant correlating parameter influencing the friction factor in the flow. Moreover, when the roughness elements are placed more closely than the previous pattern, the wake and vortex at each element will interfere with those developed at the following element, resulting in intense and complex vorticity and turbulence mixing. Note that the average depth, y, of flow above the crests of the elements will partly control the vertical extent of the surface region of abnormal turbulence. In wake-interference flow, the pitch-to-depth ratio will be an essential correlating parameter. Lastly, when the roughness elements are closely placed to each other, flow essentially skims the crests of the elements. The grooves between elements will be filled with dead water containing stable eddies, creating a pseudo wall. Large roughness projections are absent from this pseudo wall, and the surface acts *hydraulically smooth*.

In addition, the derivation of *friction velocity* or *shear velocity* from the shear stress concept is stated in Eq. (11):

$$u_* = \sqrt{\tau_0/\rho} = \sqrt{gR_hS_0} \tag{11}$$

In this equation, u_* is friction velocity or shear velocity, τ represents wall shear stress, S_0 represents channel bottom slope.

The general theoretical equation was driven for the mean velocity of uniform flow in open channels.

$$V = u_*(A_0 + 5.75log\frac{mR_h}{y_0}) \tag{12}$$

In this equation, V is the mean velocity, A_0 is the overall constant, *m* is derived from Nikuradse's experimental data, and y_0 is water depth.

For rough channels, from Keulegan's study of Bazin's data (H. Darcy, H. Bazin, 1865), the value of mean A_0 is 6.25.

$$V = u_*(6.25 + 5.75log\frac{R_h}{k_s}) \tag{13}$$

In this equation, k_s represents equivalent sand roughness.

Iwagaki (1953) conducted a further study. Resistance to turbulent flow in open channels becomes larger than that in pipes with increased Froude Number. It is due to the increased instability of the free surface at high Froude Numbers. Presented data by Iwagaki helped researchers to introduce the effect of free-surface instability on Keulegan's equations by assuming that the constants in the equations are functions of the Froude Number. The equation stated above for rough channels rearranged as follows:

$$V = u_*(A_r + 5.75log\frac{R_h}{k_s}) \tag{14}$$

In this equation, A_r is function of Froude Number shown in Fig. 2.3 as an original representation for rough channels. Also, Fig. 2.3 shows A_s values which are smooth channel values of A_r.

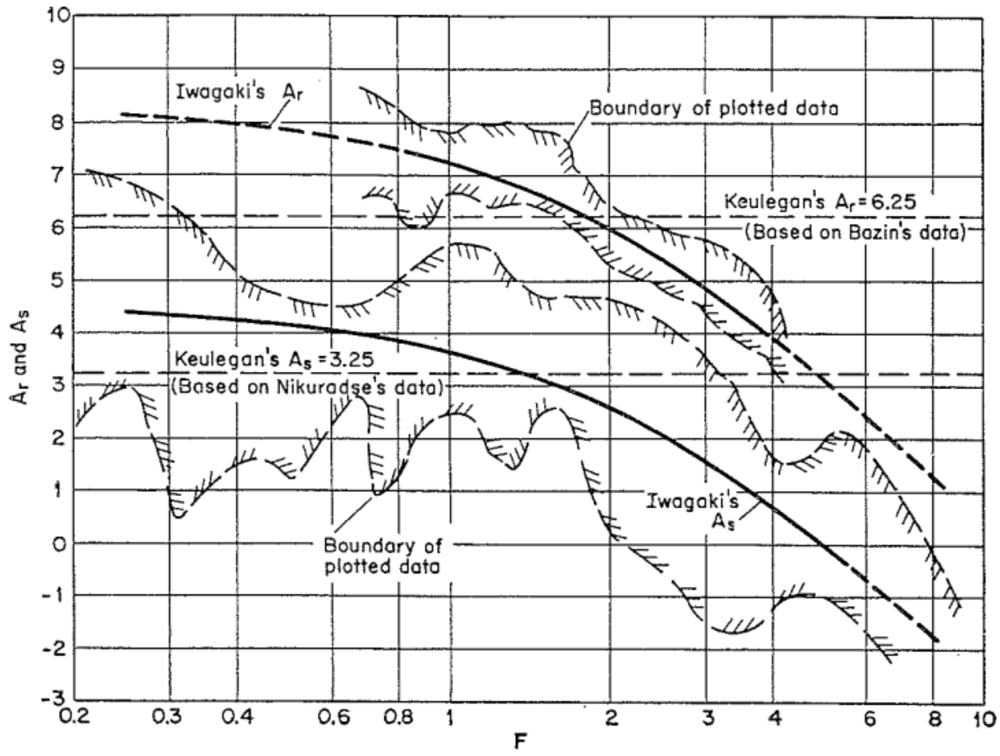

Figure 2.3 Relations among A_r, A_s and Froude Number (Chow, 1959)

From this original representation, A_r values were read and equation for A_r as function of Froude Number is derived from the best fitted curve given in Fig. 2.4 and Eq. (15).

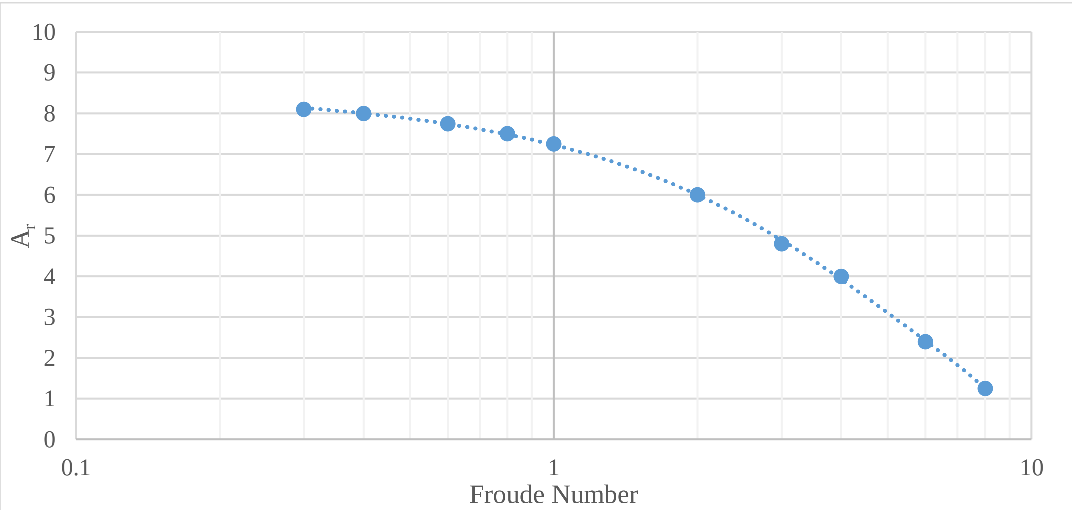

Figure 2.4 Best Fitted of A_r Values

$$A_r = -0.001Fr^4 + 0.0143Fr^3 - 0.0024Fr^2 - 1.3072Fr + 8.5222 \qquad (15)$$

Limits of application of this equation are $0.2 < Fr < 8$.

The best-fit function obtained above will be used in the analysis of experimental data obtained in this study. Experimental setup and all the related calculations will be given in CHAPTER 3, analysis of these experiments and results & discussion will be given in CHAPTER 4. Lastly, conclusions of this study will be given in CHAPTER 5.

CHAPTER 3

EXPERIMENTAL STUDY AND CALCULATION METHODOLOGY

The hydraulic model constructed in the Hydromechanics Laboratory of the Middle East Technical University, Ankara consists of channel with square bars placed on the bottom, pump, valve, flowmeter and measuring cart explained below.

3.1 Experimental Setup

3.1.1 Channel

The channel is 12 m long, 0.60 m wide and 0.4 m deep as shown in Fig. 3.1. The open-channel surfaces are made up of glass. Its downstream end is a free fall without a gate. Water is circulated from there to the underground pool.

This channel is supported by steel framing connected to the upstream end of the reservoir. Also, the channel has pin support at the upstream end and roller support at two-thirds of the length as shown in Fig. 3.2. At the roller support location, a lift is used for adjusting the channel bed slope. The desired slope is adjusted using the vernier connected at the end of the channel.

In addition, at the entrance of the channel, there are several vertical plates to smoothen the inlet flow.

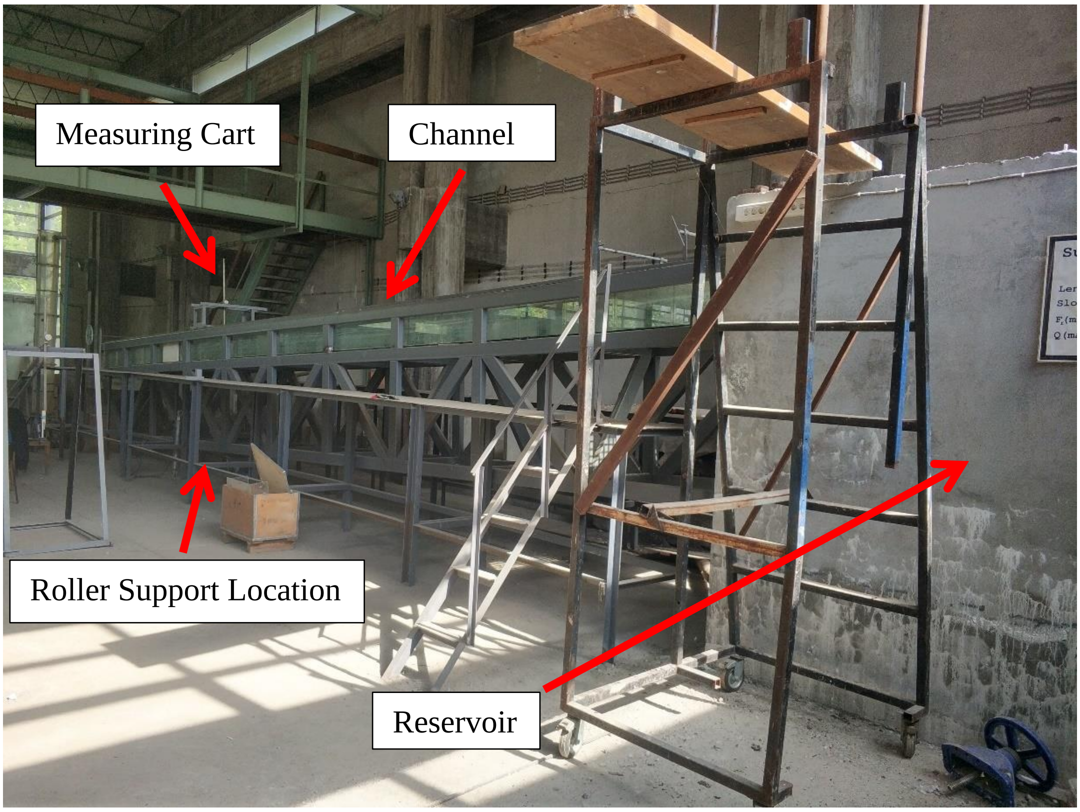

Figure 3.1 Experimental Setup

Figure 3.2 Roller Support (Lift)

3.1.2 Square Bars

Square bars, which have 60 cm length, 1 cm width, and 1 cm height, are placed on the bottom of the channel with different spacing patterns to introduce different types of roughness, Fig. 3.3. Dimensions of the square bars were determined to have easier placement and calculation.

Figure 3.3 Square Bars Placed on the Channel Bed

3.1.3 Pump, Valve and Flowmeter

Water is circulated from the underground pool to the reservoir using a pump that has a maximum capacity of 170 l/s. A DN200 valve controls discharge. Adjusted discharge can be monitored using the magnetic flowmeter as shown in Fig. 3.4.

Figure 3.4 Magnetic Flowmeter

3.1.4 Measurement Cart

A movable frame connected to the channel side walls is used for the measurements. This frame can be rolled along the channel. Water heights can be measured with a point gauge mounted on this frame as shown in Fig. 3.5. Water surface profile data are collected using this device.

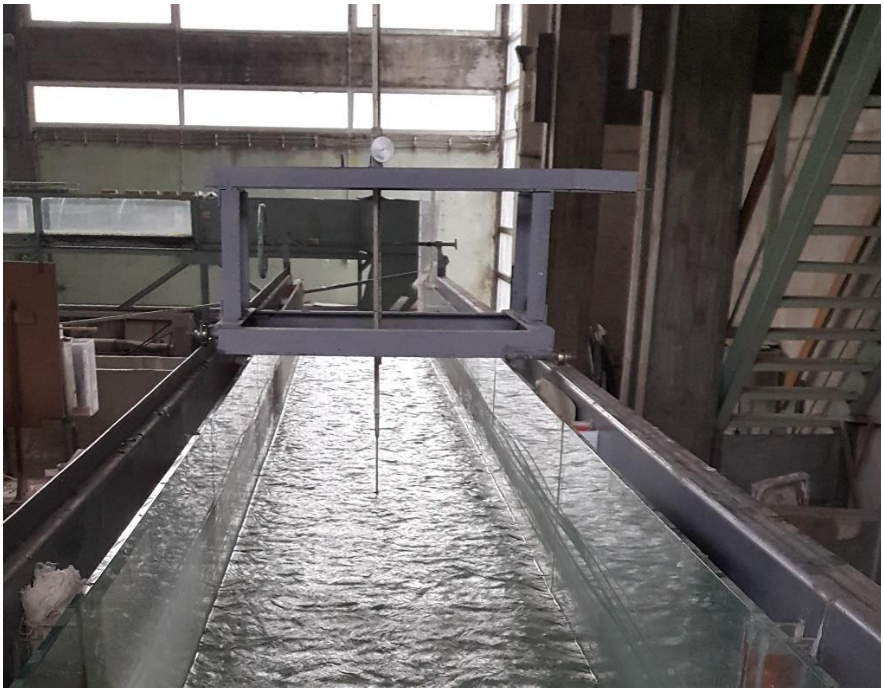

Figure 3.5 Measuring Cart

There is a ruler that has 0.1 mm accuracy placed at the side of the cart. When the point gauge touches the water surface, one can subtract the elevation read on the ruler from the elevation of the bottom of the channel for the water depth.

3.2 Experimental Programme

Experiments were conducted for five different spacing between bars. A set of water surface profile measurements for different bed slopes and discharges were conducted. Bar spacing for each case is given in Table 3.1.

Table 3.1 Bar Spacing for Test Cases

Roughness Type	Spacing Ratio (p/k)	Short Name
1	32	R1
2	16	R2
3	8	R3
4	4	R4
5	2	R5

These distances were chosen to find a peak roughness value. p/k=2 is the minimum available ratio, and ease of adding or removing bars was considered for practical reasons.

3.3 Data Collection

Data collection according to the above patterns was done on the experimental setup. A point gauge was attached to a moving cart on the rails mounted on the side walls of the channel in Fig. 3.6. The sensitivity of the point gauge used to measure water levels is 0.1 mm. Water levels were measured on stations fixed at every 0.25 m along the channel.

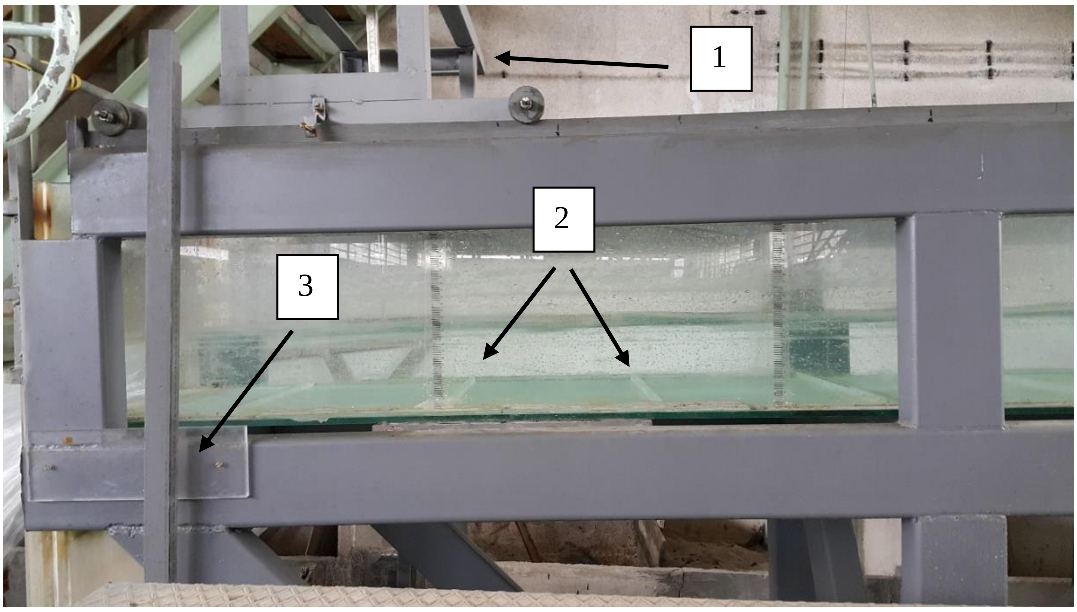

Figure 3.6 Measuring Cart and Ribs on the Channel Bed

The cart carrying the point gauge is shown in the upper left corner as 1. Rib roughness elements are numbered 2. Moreover, the scale to read the channel slope fixed on the vertical stud can be seen as number 3.

During the data collection stage, some measurement errors may occur due to the reasons listed:

- Oscillations in the monitor of discharge measuring acoustic device
- Oscillations in water surface elevation

After preliminary analysis, data from the uniform flow section of the channel were used in the study. The data collected from the channel entrance and end affected regions were discarded.

3.4 Experimental Procedure

Experiments were conducted in a sequential order. First, channel slope was adjusted using roller support in specific roughness pattern. Then, bottom outlet of the reservoir was closed to fill the reservoir. After that, magnetic flowmeter and pump were opened. Desired discharge was adjusted using valve. Finally, using measurement cart, water height measurements were. Channel bottom slopes and discharges for each test case are given in Tables 3.2 to Table 3.6. In total, 507 experiments were conducted.

Table 3.2 R1 Experiments

	Slopes				
	0.030	**0.035**	**0.040**	**0.045**	**0.050**
Discharges (m^3/s)	0.041	0.070	0.044	0.071	0.044
	0.051	0.082	0.062	0.084	0.056
	0.062	0.093	0.074	0.095	0.070
	0.074	0.106	0.086	0.105	0.084
	0.088	0.117	0.095	0.116	0.100
	0.102	0.129	0.106	0.126	0.112
	0.116	0.140	0.117	0.136	0.123
	0.131	0.155	0.130	0.148	0.133

Table 3.3 R2 Experiments

	Slopes								
	0.010	**0.015**	**0.020**	**0.025**	**0.030**	**0.035**	**0.040**	**0.045**	**0.050**
Discharges (m^3/s)	0.014	0.014	0.013	0.013	0.012	0.013	0.013	0.012	0.012
	0.024	0.025	0.025	0.023	0.022	0.023	0.025	0.021	0.023
	0.036	0.036	0.036	0.033	0.033	0.033	0.036	0.033	0.032
	0.046	0.047	0.047	0.043	0.044	0.045	0.045	0.041	0.041
	0.056	0.056	0.057	0.054	0.055	0.055	0.056	0.052	0.050
	0.066	0.065	0.067	0.066	0.065	0.065	0.066	0.060	0.060
	0.076	0.075	0.078	0.079	0.076	0.076	0.076	0.070	0.072
	0.088	0.087	0.087	0.090	0.085	0.086	0.087	0.082	0.083
	0.097	0.097	0.099	0.101	0.096	0.098	0.096	0.095	0.095
	0.106	0.108	0.109	0.110	0.106	0.109	0.106	0.108	0.108
	0.117	0.118	0.120	0.121	0.116	0.118	0.118	0.120	0.118
	0.130	0.128	0.130	0.130	0.126	0.127	0.127	0.130	0.124
	0.140	0.141	0.145	0.140	0.137	0.137	0.137		0.139

Table 3.4 R3 Experiments

	Slopes								
	0.010	**0.015**	**0.020**	**0.025**	**0.030**	**0.035**	**0.040**	**0.045**	**0.050**
Discharges (m^3/s)	0.010	0.012	0.012	0.012	0.011	0.012	0.012	0.011	0.010
	0.024	0.023	0.020	0.024	0.023	0.021	0.021	0.022	0.018
	0.035	0.035	0.032	0.034	0.032	0.030	0.031	0.034	0.025
	0.043	0.044	0.043	0.042	0.041	0.042	0.040	0.043	0.034
	0.050	0.055	0.052	0.053	0.050	0.053	0.049	0.052	0.043
	0.060	0.065	0.063	0.064	0.059	0.064	0.060	0.060	0.054
	0.071	0.077	0.074	0.077	0.070	0.076	0.070	0.068	0.064
	0.081	0.087	0.083	0.089	0.082	0.088	0.082	0.079	0.072
	0.091	0.098	0.093	0.101	0.092	0.098	0.096	0.089	0.085
	0.102	0.106	0.106	0.111	0.101	0.109	0.104	0.100	0.098
	0.115	0.116	0.114	0.121	0.110	0.120	0.113	0.114	0.109
	0.125	0.128	0.126	0.133	0.121	0.133	0.125	0.125	0.124
	0.136	0.146	0.137	0.144	0.131	0.148	0.142	0.135	0.135

Table 3.5 R4 Experiments

	Slopes								
	0.010	**0.015**	**0.020**	**0.025**	**0.030**	**0.035**	**0.040**	**0.045**	**0.050**
Discharges (m^3/s)	0.012	0.012	0.010	0.010	0.011	0.011	0.010	0.010	0.013
	0.021	0.020	0.022	0.023	0.023	0.021	0.021	0.019	0.022
	0.032	0.032	0.036	0.033	0.033	0.033	0.029	0.029	0.034
	0.041	0.040	0.046	0.046	0.046	0.044	0.040	0.037	0.042
	0.050	0.048	0.057	0.060	0.058	0.054	0.049	0.050	0.051
	0.060	0.061	0.067	0.070	0.068	0.067	0.060	0.058	0.061
	0.070	0.074	0.078	0.080	0.079	0.079	0.068	0.067	0.073
	0.079	0.087	0.091	0.093	0.090	0.091	0.079	0.076	0.084
	0.091	0.097	0.102	0.106	0.101	0.103	0.087	0.086	0.093
	0.101	0.109	0.115	0.118	0.110	0.113	0.094	0.097	0.102
	0.110	0.117	0.125	0.131	0.120	0.123	0.102	0.108	0.110
	0.118	0.132	0.136	0.143	0.128	0.135	0.109	0.120	0.119
	0.127	0.145	0.147	0.154	0.139	0.147	0.117	0.132	0.134

Table 3.6 R5 Experiments

	Slopes								
	0.010	**0.015**	**0.020**	**0.025**	**0.030**	**0.035**	**0.040**	**0.045**	**0.050**
Discharges (m^3/s)	0.012	0.012	0.012	0.012	0.013	0.013	0.012	0.012	0.012
	0.022	0.022	0.023	0.024	0.022	0.025	0.023	0.023	0.022
	0.031	0.031	0.033	0.036	0.037	0.036	0.033	0.034	0.032
	0.040	0.043	0.044	0.048	0.047	0.047	0.040	0.043	0.043
	0.051	0.053	0.053	0.057	0.058	0.059	0.050	0.053	0.051
	0.063	0.063	0.063	0.067	0.068	0.070	0.060	0.064	0.062
	0.076	0.075	0.075	0.079	0.077	0.080	0.073	0.073	0.072
	0.088	0.086	0.085	0.086	0.087	0.089	0.082	0.082	0.082
	0.099	0.097	0.097	0.095	0.098	0.098	0.093	0.093	0.094
	0.112	0.109	0.107	0.106	0.108	0.109	0.106	0.105	0.106
	0.122	0.118	0.117	0.115	0.118	0.120	0.117	0.116	0.116
	0.132	0.129	0.128	0.126	0.127	0.128	0.126	0.127	0.126
	0.145	0.140	0.140	0.138	0.137	0.139	0.142	0.137	0.138

3.5 Calculation Procedure

As listed before, five different sets of experiments were conducted for variable discharges on different channel slopes. The following calculations have been done for each test case:

- First, a water surface profile is drawn. In R1, there were 18 valid water-level data, since they were measured with 50 cm spacing, channel length allows that much of data. After analysis, it was understood that they needed more to obtain a proper surface profile. Thus, it was agreed to take measurements, not in every 50 cm but every 25 cm spacing along the channel.
- Then, eliminating the data from nonuniform parts, the water surface is obtained from the uniform flow portion.
    - After analysing the R1 results, the channel and surface slopes were compared, and it was understood that they were almost equal. Thus, it was agreed that in the following roughness types, one of the water surface profiles was obtained to prove it, and in the other discharges, channel bed slopes were taken as the water surface slope.
- Water depth is measured from a point in the middle of the uniform flow section and recorded as uniform flow depth.
- After obtaining the uniform flow depth, y_n, one should keep in mind that the actual uniform flow depth, y_a, is different from y_n because an upward shift occurs due to the roughness elements placed on the bottom of the surface. As shown in Fig. 3.7. The measured value of uniform flow depth is corrected to account for the bed shift due to rib elements on the bed using Eq. (16). Shift in bed elevation, Δz, can be obtained using Eq. (17).

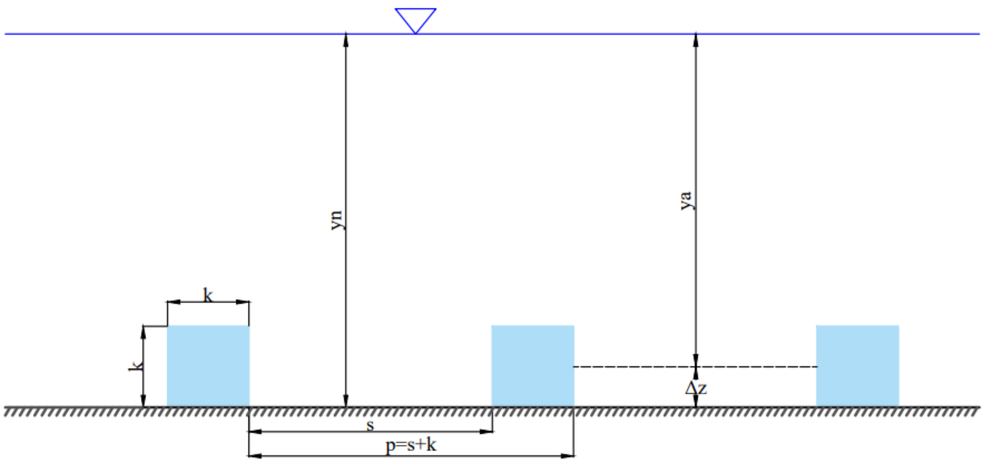

Figure 3.7 Representation of Actual Flow Depth

$$y_a = \frac{\text{water filled area}}{\text{channel segment length}} = \frac{y_n s + (y_n - k)k}{s + k} \tag{16}$$

In this equation, y_a is the actual uniform flow depth, *s* represents rib spacing, and *k* represents rib height. The correction given by Eq. (16) is asymptotic to smooth surface in both limiting cases as s approaching zero and infinity. Pitch ratio is defined as p/k where p=s+k.,

$$\Delta z = y_n - y_a \tag{17}$$

Using y_a, hydraulic radius and average velocity were calculated.

- After calculating the hydraulic radius, the average wall shear stress for the complete wetted perimeter of the channel was calculated.
- Bed and side shear stresses should be found to understand the properties of roughness elements better. Because the side walls of the channel were made of glass, one can treat it as a smooth channel and use the specified discharge and values for y_a to calculate the water surface slope, as well as related values such as shear stress and shear force, using Manning's Equation with a roughness coefficient of n=0.01 for glass. Afterwards, bed shear stress and shear force values on the bed were calculated.
- Since shear stress for bed resistance is known, shear velocity was calculated.

- Also, hydraulic depth and Froude Number were calculated.
- Using this Froude Number and Iwagaki's Equation, Eq. (14), the surface roughness value, k_s, was calculated.
- In addition, using Manning's Equation, Equivalent Manning's n Coefficient was calculated using Eq. 18, stated by Djajadi (2009).

$$n_{eqv} = \sqrt{\frac{2 * (n_{glass})^2 * y_a + (n_{bed})^2 * b}{b + 2 * y_a}} \tag{18}$$

In this equation, n_{glass} is Manning's n coefficient of glass material, which is 0.01, and b is channel width.

- Also, Reynolds Number, y_a/k and k_s/ y_a values were calculated.

3.6 Calculation Steps

All water depth measurements will be analysed in this section according to the Calculation Procedure Section. Step-by-step formulations will be presented using the data of R3 measurements for S_0=0.010.

Firstly, the channel slope has been adjusted to the value of 0.010, and channel bed elevations at each measuring station are measured. After that, the discharge was set to a value of 50 lt/s. And then, water surface elevations at each station were measured. Then water depths, y_n values, were calculated as the difference between the bed and water surface elevations. After that, y_a values have been calculated using Eqn. (16). z_a values, which include the channel bottom slope along the channel considering start and end elevation difference, have been calculated from the datum using the current channel slope. An example can be seen in Table 3.7.

Table 3.7 Example Measurements

Slope: 0.010					
Station	Bed Elevation (cm)	Water Surface Elevation	y_n (cm)	y_a (cm)	z_a (cm) (from datum)
1	33.94	44.28	10.34	10.22	10.67
2	33.87	44.75	10.88	10.76	11.46
3	33.83	44.87	11.04	10.92	11.87
4	33.78	45.03	11.25	11.13	12.33
5	33.76	45.17	11.41	11.29	12.74
6	33.74	45.37	11.63	11.51	13.21
7	33.74	45.38	11.64	11.52	13.47
8	33.69	45.55	11.86	11.74	13.89
9	33.76	45.31	11.55	11.43	13.88
10	33.67	45.42	11.75	11.63	14.33
11	33.67	45.47	11.80	11.68	14.63
12	33.64	45.51	11.87	11.75	14.95
13	33.66	45.42	11.76	11.64	15.09
14	33.61	45.64	12.03	11.91	15.61
15	33.63	45.52	11.89	11.77	15.72
16	33.66	45.64	11.98	11.86	16.06
17	33.63	45.63	12.00	11.88	16.33
18	33.62	45.53	11.91	11.79	16.49
19	33.72	45.73	12.01	11.89	16.84
20	33.65	45.76	12.11	11.99	17.19
21	33.55	45.83	12.28	12.16	17.61
22	33.99	45.73	11.74	11.62	17.32
23	33.79	45.56	11.77	11.65	17.60
24	34.03	45.67	11.64	11.52	17.72
25	33.95	45.83	11.88	11.76	18.21
26	34.10	45.93	11.83	11.71	18.41
27	34.05	45.95	11.90	11.78	18.73
28	34.10	45.99	11.89	11.77	18.97
29	34.07	46.07	12.00	11.88	19.33
30	34.01	46.24	12.23	12.11	19.81
31	33.98	46.14	12.16	12.04	20.04
32	34.06	46.15	12.09	11.97	20.17
33	34.11	46.09	11.98	11.86	20.31
34	34.06	46.16	12.10	11.98	20.68
35	34.02	46.11	12.09	11.97	20.92
36	34.11	46.02	11.91	11.79	20.99
37	34.01	45.89	11.88	11.76	21.21

One should take tilted channel slope into account. Since surface slope of the water will be investigated, original channel position should be taken as datum. For example, water height at Station 17 has been calculated as below:

Measured water depth at Station 17 = 12.00 cm

Distance from the rotation point, i.e. beginning of the channel = 755 cm

Total length of the channel = 1,200 cm and Channel Slope = 0.010

y_a = [12*1+(12-1)*1]/(7+1) = 11.88 cm

y_a (considering channel slope datum) = 11.88 + (1,200*0.01-1,200*0.01*755/1,200) = 16.33 cm

Here, 1,200*0.01 means that maximum tip tilt height of the channel. And it changes with respect to the slope of the channel. And all the other water depths have been calculated in this manner.

After these calculations, the water surface slope is calculated by plotting z_a against horizontal distance. Water surface slope is determined by excluding the non-uniform parts of the flow as shown in Fig. 3.8.

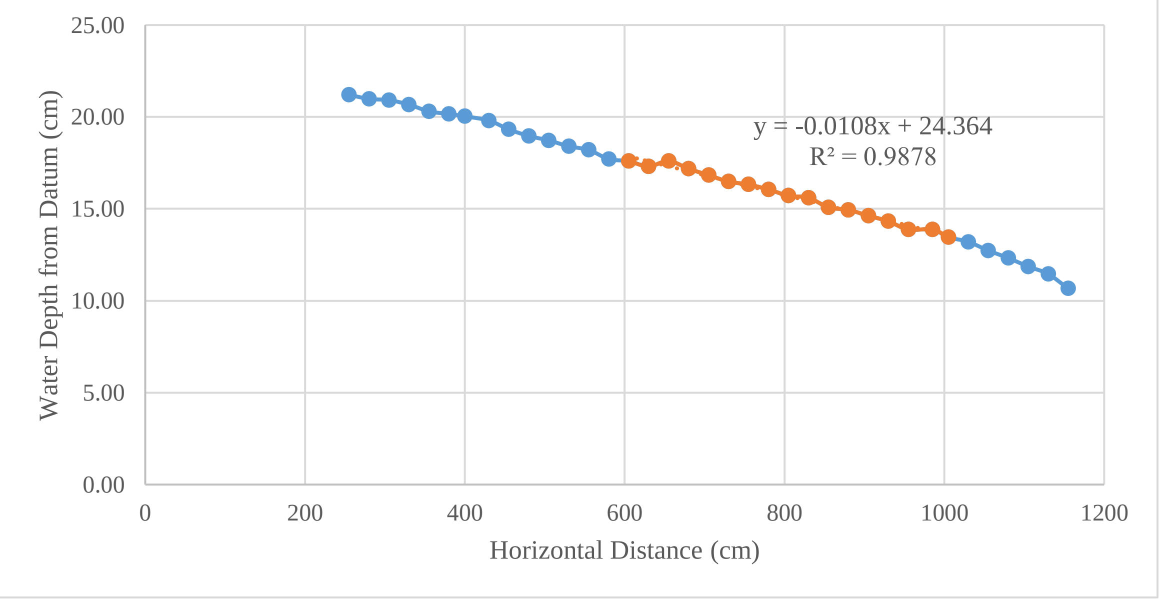

Figure 3.8 Water Surface Profile

Then one can add a linear best-fit line to the given portion. This line's slope gives the water surface slope of the flow. The expected slope was 0.010, but some errors may be introduced during measurements.

The channel and surface slopes were compared, and it was observed that they were almost equal. Thus, it was agreed that in the following roughness types, one of the water surface profiles was obtained to prove it, and in the other discharges, channel bed slope was taken as water surface slope.

Water depth was calculated using the data at the middle of the uniform portion which is the 805 cm length of the channel. This point has been used in the best line equation and the y value gives the uniform water depth of this discharge as follows:

$$y = -0.108 * x + 24.363 - (12 - 12 * 805/1200) \tag{19}$$

$$x = 805\ cm$$

$$y_a = 0.117\ m$$

As mentioned above, for different discharges, this procedure has been left and instead of water surface slope of flow, one can use bed slope of channel.

After determining uniform flow depth, one can compute the hydraulic radius, hydraulic diameter, and average velocity.

$$R_h = A/P \tag{20}$$

In this equation, A is uniform flow area.

$$R_h = 0.118 * 0.6/(2 * 0.118 + 0.6)$$

$$R_h = 0.0843\ m$$

$$Q = V * A \tag{21}$$

In this equation, Q is discharge, V is average velocity.

$$50/1000 = V * (0.118 * 0.6)$$

$$V = 0.711\ m/s$$

$$\tau_w = \gamma_w * R_h * S_0 \tag{22}$$

$$\tau_w = 9810 * 0.0849 * 0.01$$

$$\tau_w = 8.27\ Pa$$

$$F_{total} = \tau_w P \tag{23}$$

$$F_{total} = 8.27 * (0.6 + 2 * 0.117) = 6.90\ N/m$$

In this equation, F_{total} represents the total shear force acting on all wetted surfaces.

$$Q = \frac{A}{n_{glass}} R_h^{\frac{2}{3}} \sqrt{S_s} \tag{24}$$

In this equation, S_s represents the slope for the smooth case. Using Eq. (24), the slope required for the smooth case can be determined using n_{glass}=0.01.

$$S_s = 0.00137$$

After that, using Eq. (22) with that slope value, the side surfaces shear stress value can be determined.

$$\tau_{w,smooth} = \gamma_w R_h S_s \tag{25}$$

$$\tau_{w,smooth} = 9810 * 0.0843 * 0.00137$$

$$\tau_{w,smooth} = 1.13\ Pa$$

$$F_{side} = \tau_{w,smooth} y_a \tag{26}$$

$$F_{side} = 1.13 * 0.117 = 0.13\ N/m$$

Using Eq. (26), the force exerted on the side wall of the channel can be determined. Then, subtracting two side wall forces from the total force will end up with only force exerted on the channel bed.

$$F_{bed} = F_{total} - 2 * F_{side} \tag{27}$$

$$F_{bed} = 6.90 - 2 * 0.13 = 6.63\ N/m$$

$$\tau_{w,bed} = F_{bed}/b_w \tag{28}$$

$$\tau_{w,bed} = 6.63/0.6\ = 11.06\ Pa$$

Dividing force exerted on the channel bed to channel width, b_w, will result in bed shear stress. As mentioned before, Eq. (8), Eq. (9) and Eq. (10) and this approach will be compared. These three side wall correction methods were found from literature.

To compare all four approaches, R3 experiments when S=0.010 data were used, and tabular form of the comparison stated in Table 3.8.

Table 3.8 Correction Methods Comparison Table

	τ_{bed} (Pa)			
Discharge (m^3/s)	Eq. (8)	Eq. (9)	Eq. (10)	Current Method
0.010	5.05	5.05	5.06	5.09
0.024	7.75	7.76	7.77	7.83
0.035	9.32	9.35	9.37	9.45
0.043	10.21	10.24	10.27	10.36
0.050	11.79	11.84	11.87	11.06
0.060	12.01	12.08	12.11	12.22
0.071	13.16	13.25	13.29	13.41
0.081	13.95	14.06	14.10	14.23
0.091	14.73	14.86	14.90	15.04
0.102	15.84	16.00	16.03	16.19
0.115	16.90	17.09	17.12	17.29
0.125	17.69	17.91	17.94	18.12
0.136	18.43	18.68	18.71	18.89

These four methods were compared, and it was seen that there was not a dramatic difference among each method. Thus, current method was accepted.

This bed shear stress which was calculated using Eq. (28) will be used to calculate shear velocity as formulated in Eq. (29):

$$u_* = \sqrt{\tau_{w,bed}/\rho} \tag{29}$$

$$u_* = \sqrt{11.06/1000} = 0.11\ m/s$$

Also, Froude Number can be calculated using Eq. (30). Then using Eq. (15), A_r value can be obtained.

$$Fr = V\sqrt{gD_h} \tag{30}$$

$$D_h = \mathrm{A/T} \tag{31}$$

$$D_h = 0.117 * 0.6/0.6 = 0.117\ m$$

$$Fr = 0.711 * \sqrt{9.81 * 0.117} = 0.66$$

In Eq. (30), D_h is hydraulic depth and in Eq. (31) T is water surface width.

$$A_r = -0.001 * Fr^4 + 0.0143 * Fr^3 - 0.0024 * Fr^2 - 1.3072 * Fr + 8.522$$

$$A_r = -0.001 * 0.66^4 + 0.0143 * 0.66^3 - 0.0024 * 0.66^2 - 1.3072 * 0.66 + 8.522$$

$$A_r = 7.66$$

After the A_r value calculation, one can calculate the k_s value using Eq. (14) with rearrangements.

$$k_s = \frac{R_h}{10^{(V/u_* - A_r)/5.75}} \tag{32}$$

$$k_s = \frac{0.0843}{10^{(0.711/0.11 - 7.66)/5.75}}$$

$$k_s = 0.1206\ m$$

Moreover, using Eq. (5), Manning's Equation, the equivalent Manning's n value for the whole channel can be calculated.

$$Q = \frac{\mathrm{A}}{n_{eqv}} R^{\frac{2}{3}} \sqrt{S_0} \tag{33}$$

$$n_{eqv} = 0.0281$$

Also, one should note that this value is the equivalent of Manning's n value, which consist of all the surfaces, including smooth side glass surfaces and rough bed surface. However, bed Manning's n value is the value to be determined. Thus, using Eq. (18), it can be calculated.

$$n_{eqv} = \sqrt{\frac{n_{bed}^2 * P_{bed} + n_{glass}^2 * P_{glass}}{P_{total}}} \tag{34}$$

$$0.0281 = \sqrt{\frac{n_{bed}^2 * 0.60 + 0.01^2 * (2 * 0.117)}{(2 * 0.117 + 0.6)}}$$

$$n_{bed} = 0.0325$$

In addition to these calculations, *Reynolds Number*, y_a/k, and k_s/y_a ratios can be calculated. Reynolds Number is used to determine the flow regime of the fluid flow.

$$Re = \frac{V * D_h}{\nu} \tag{35}$$

$$\nu = 10^{-6}\, m^2/s$$

$$Re = \frac{0.711 * 0.3371}{10^{-6}}$$

$$Re = 239{,}643$$

$$\frac{y_a}{k} = \frac{0.117}{0.010} = 11.72$$

$$\frac{k_s}{y_a} = \frac{0.1201}{0.1170} = 1.0294$$

For R3, S=0.010 experiments calculation table is given in Table 3.10 to Table 3.12.

Table 3.9 Example Calculation Table

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Average Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0100	0.054	0.052	5.23	0.318	0.0446	4.37
0.024	0.0100	0.083	0.082	8.15	0.491	0.0641	6.29
0.035	0.0100	0.100	0.099	9.90	0.589	0.0745	7.30
0.043	0.0100	0.111	0.109	10.93	0.656	0.0801	7.86
0.050	0.0108	0.118	0.117	11.72	0.711	0.0843	8.27
0.060	0.0100	0.132	0.130	13.03	0.767	0.0908	8.91
0.071	0.0100	0.145	0.144	14.38	0.823	0.0972	9.54
0.081	0.0100	0.155	0.154	15.36	0.879	0.1016	9.96
0.091	0.0100	0.165	0.163	16.33	0.929	0.1057	10.37
0.102	0.0100	0.178	0.176	17.64	0.964	0.1111	10.90
0.115	0.0100	0.191	0.190	18.95	1.011	0.1161	11.39
0.125	0.0100	0.201	0.199	19.94	1.045	0.1198	11.75
0.136	0.0100	0.210	0.209	20.91	1.084	0.1232	12.09

Table 3.10 Example Calculation Table Continued

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00064	0.28	0.01	3.08	3.05	5.09	0.07
0.00094	0.59	0.05	4.80	4.70	7.83	0.09
0.00111	0.81	0.08	5.83	5.67	9.45	0.10
0.00125	0.98	0.11	6.43	6.22	10.36	0.10
0.00137	1.13	0.13	6.90	6.63	11.06	0.11
0.00144	1.29	0.17	7.67	7.33	12.22	0.11
0.00152	1.44	0.21	8.46	8.05	13.41	0.12
0.00163	1.63	0.25	9.04	8.54	14.23	0.12
0.00173	1.79	0.29	9.61	9.02	15.04	0.12
0.00174	1.90	0.33	10.38	9.71	16.19	0.13
0.00181	2.06	0.39	11.15	10.37	17.29	0.13
0.00185	2.17	0.43	11.74	10.87	18.12	0.13
0.00192	2.32	0.48	12.30	11.34	18.89	0.14

Table 3.11 Example Calculation Table Continued

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.44	7.94	0.1795	0.0395	0.0426	56762
0.08	0.55	7.81	0.1585	0.0326	0.0364	125819
0.10	0.60	7.74	0.1462	0.0301	0.0342	175417
0.11	0.63	7.70	0.1322	0.0283	0.0325	210141
0.12	0.66	7.66	0.1206	0.0281	0.0325	239693
0.13	0.68	7.64	0.1201	0.0263	0.0308	278875
0.14	0.69	7.62	0.1195	0.0257	0.0305	319964
0.15	0.72	7.59	0.1109	0.0248	0.0296	357182
0.16	0.73	7.57	0.1053	0.0241	0.0290	392876
0.18	0.73	7.57	0.1108	0.0240	0.0292	428212
0.19	0.74	7.56	0.1100	0.0235	0.0290	469867
0.20	0.75	7.55	0.1100	0.0233	0.0289	500601
0.21	0.76	7.54	0.1070	0.0228	0.0286	534329

3.7 Dimensional Analysis

The surface roughness, k_s, of the channel bed can be defined as a function of several parameters expressed in Eq. (36).

$$k_s = f(V, y_a, k, p, g, \rho, \mu) \tag{36}$$

In this equation, V is average velocity, y_a is actual uniform flow depth, k is rib height, p is pitch distance, g is gravitational acceleration, ρ is density of water and μ is dynamic viscosity of water. At first, analysis will be done for a given spacing, p, to obtain k_s for a specific pattern. Thus, excluding p from the list:

$$n = 7, \qquad k = 3, \qquad m = n - k = 4$$

and choosing the repeating variables as V, y_a and ρ, the set of independent dimensionless groups are obtained.

$$\prod_1 = y_a/k = Relative\ Depth \tag{37}$$

$$\prod_2 = k_s/y_a = Relative\ Roughness \tag{38}$$

$$\prod_3 = V y_a \rho/\mu = Reynolds\ Number \tag{39}$$

$$\prod_4 = V/(g^{\frac{1}{2}} y_a{}^{\frac{1}{2}}) = Froude\ Number \tag{40}$$

Relative depth and relative roughness values will be used in upcoming sections. The dimensionless variable *p/k* is also added in the analysis of the experimental data.

CHAPTER 4

ANALYSIS OF RESULTS

4.1 Data Analysis

Procedure described in Chapter 3.6 was applied to different discharges in a specific slope value. After that, the slope was changed, and this procedure was applied again. When all the slope values were completed, the roughness pattern was adjusted, and all the procedures were applied again.

As a result, the data set that consists of y_a/k vs k_s/y_a was collected and graphs for each roughness pattern were drawn in Fig. 4.1 to Fig. 4.5.

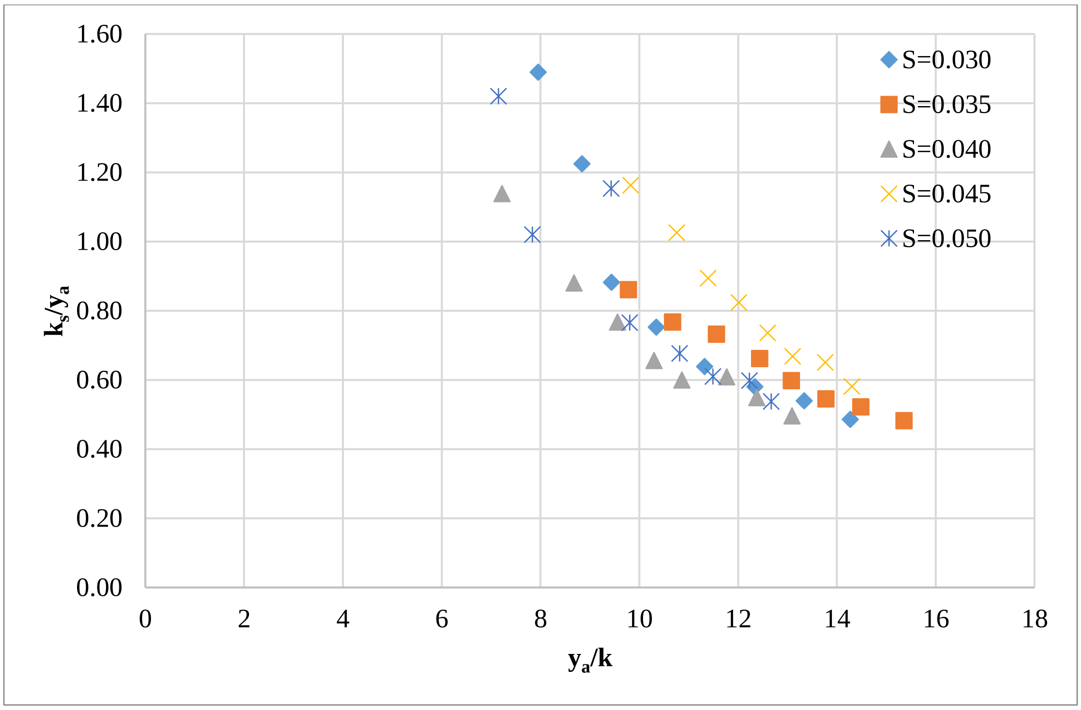

Figure 4.1 y_a/k vs k_s/y_a for R1 (p/k=32)

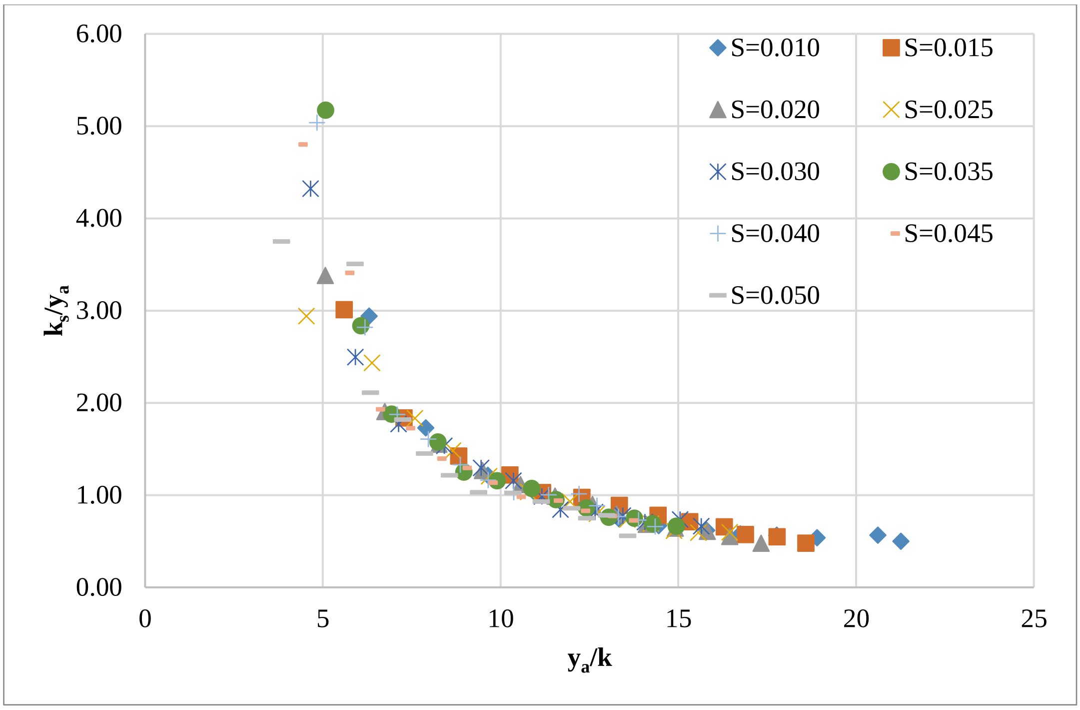

Figure 4.2 y_a/k vs k_s/y_a for R2 (p/k=16)

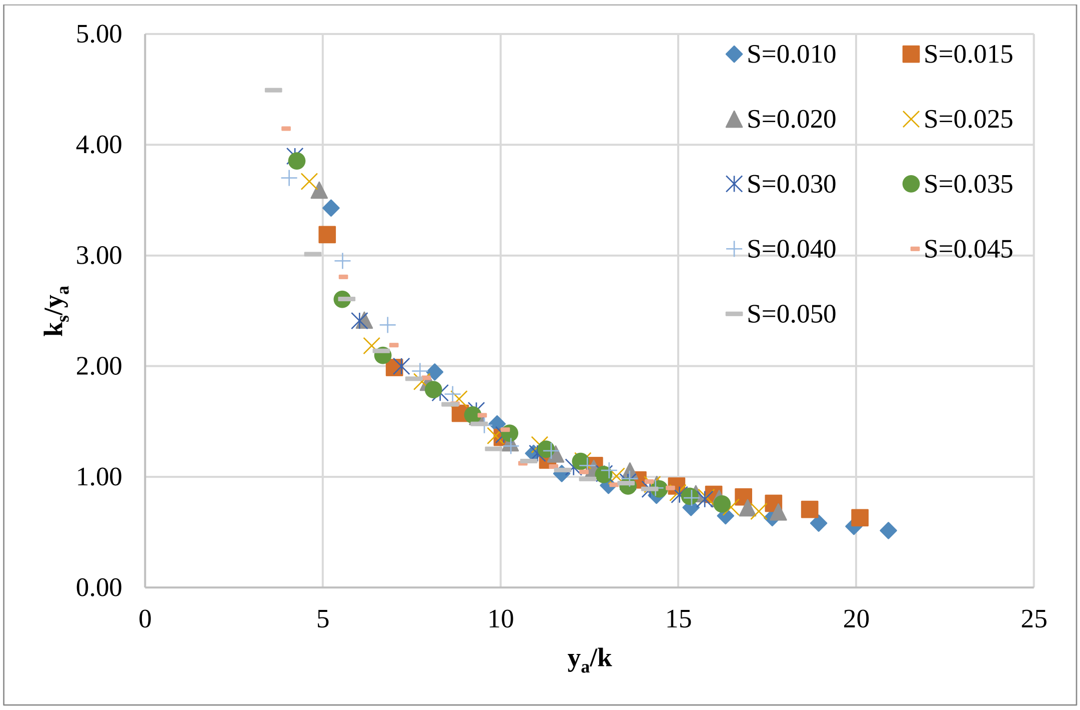

Figure 4.3 y_a/k vs k_s/y_a for R3 (p/k=8)

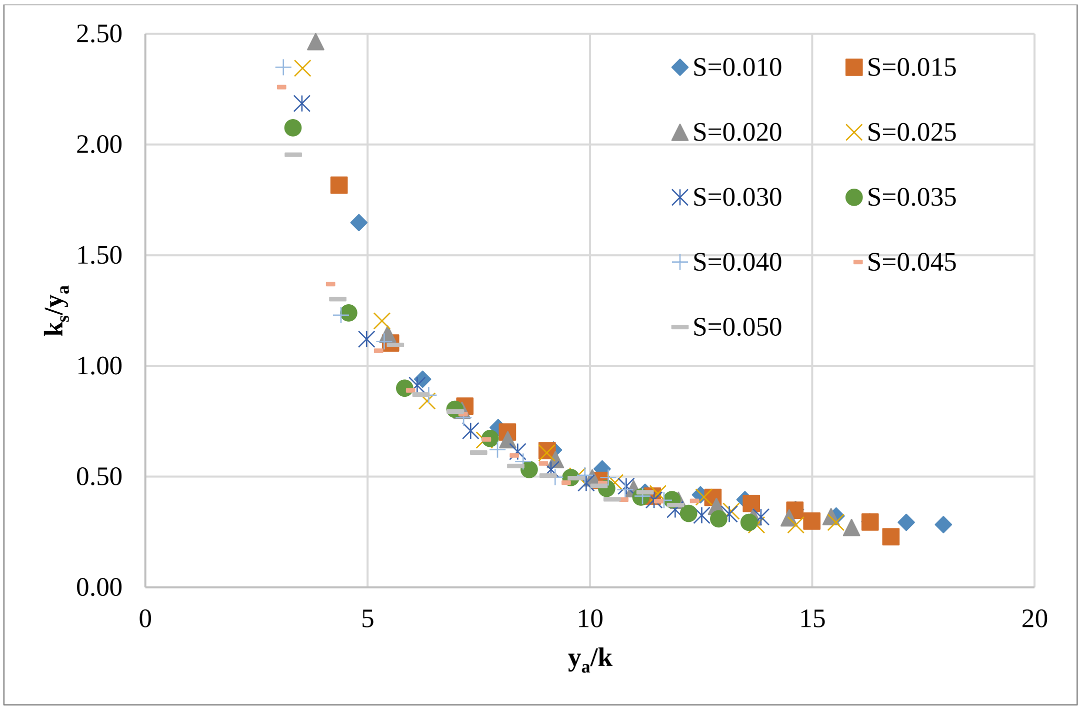

Figure 4.4 y_a/k vs k_s/y_a for R4 (p/k=4)

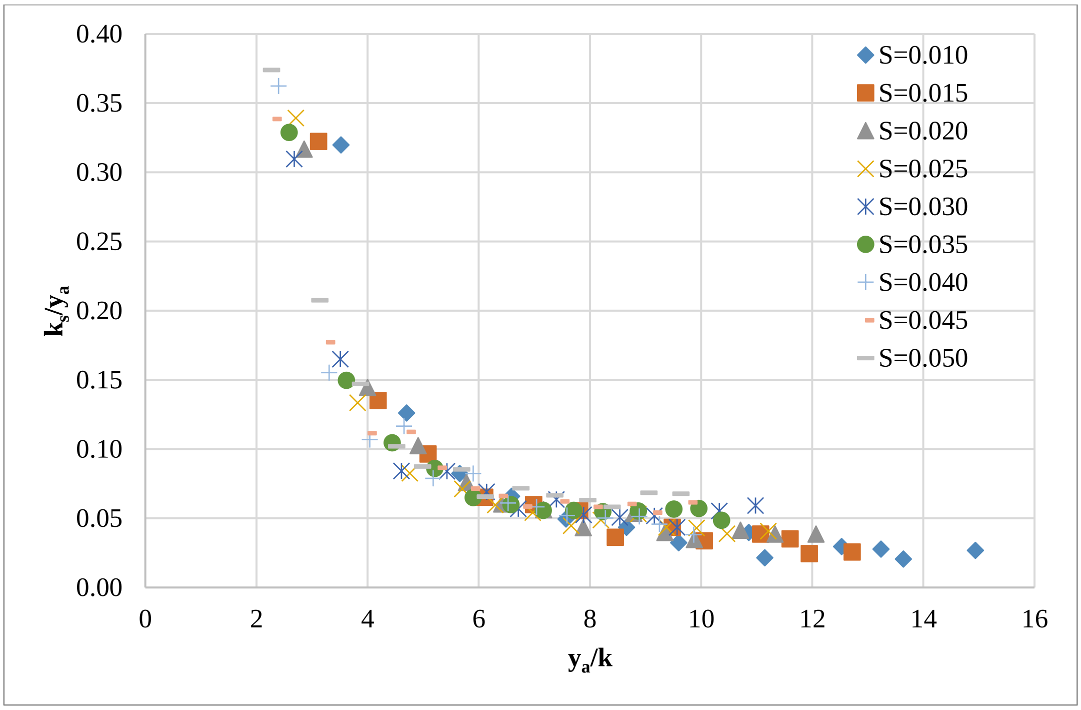

Figure 4.5 y_a/k vs k_s/y_a for R5 (p/k=2)

4.2 Interpretation of Graphs

All the graphs given in the Section 4.1 were created using relative depth and relative roughness values. There is a relationship in between these two values. Also, these graphs show that for each slope, even though Reynolds Number and Froude Number were variable, clustering happened in graphs. This means that, surface roughness value is independent from Reynolds Number and Froude Number.

After obtaining roughness-spacing graphs for all cases, best-fit curves are obtained. Best-fit functions in the form of power functions with a common exponent for all cases are given in Figs. 4.6-4.10.

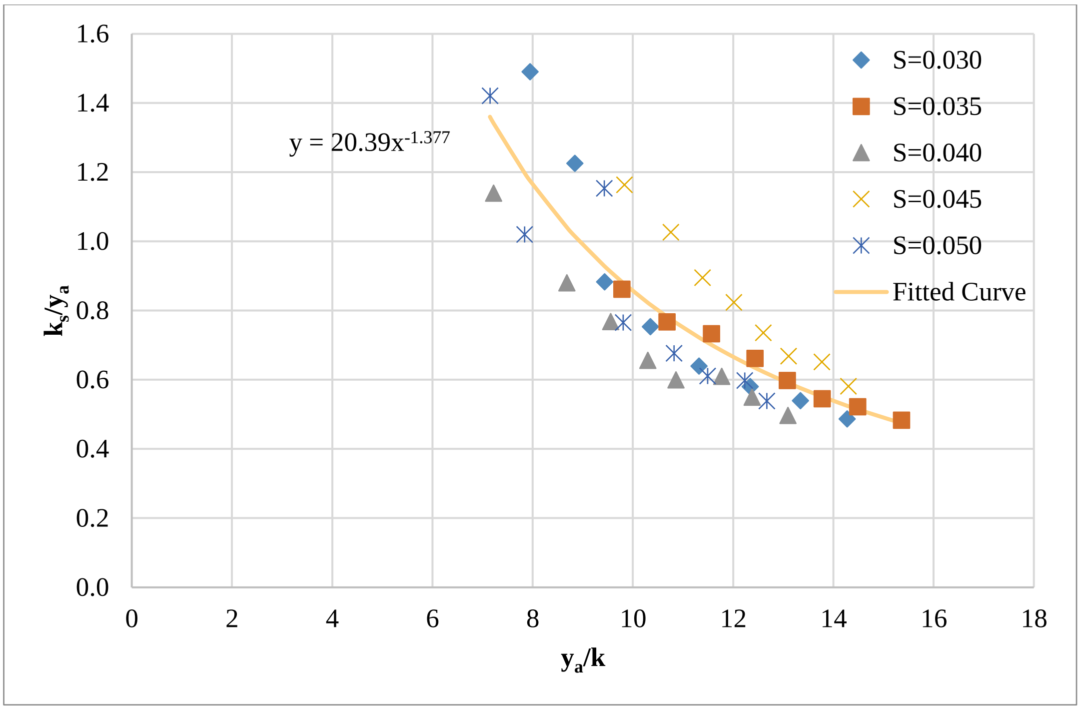

Figure 4.6 Curve Fitted y_a/k vs k_s/y_a for R1 (p/k=32)

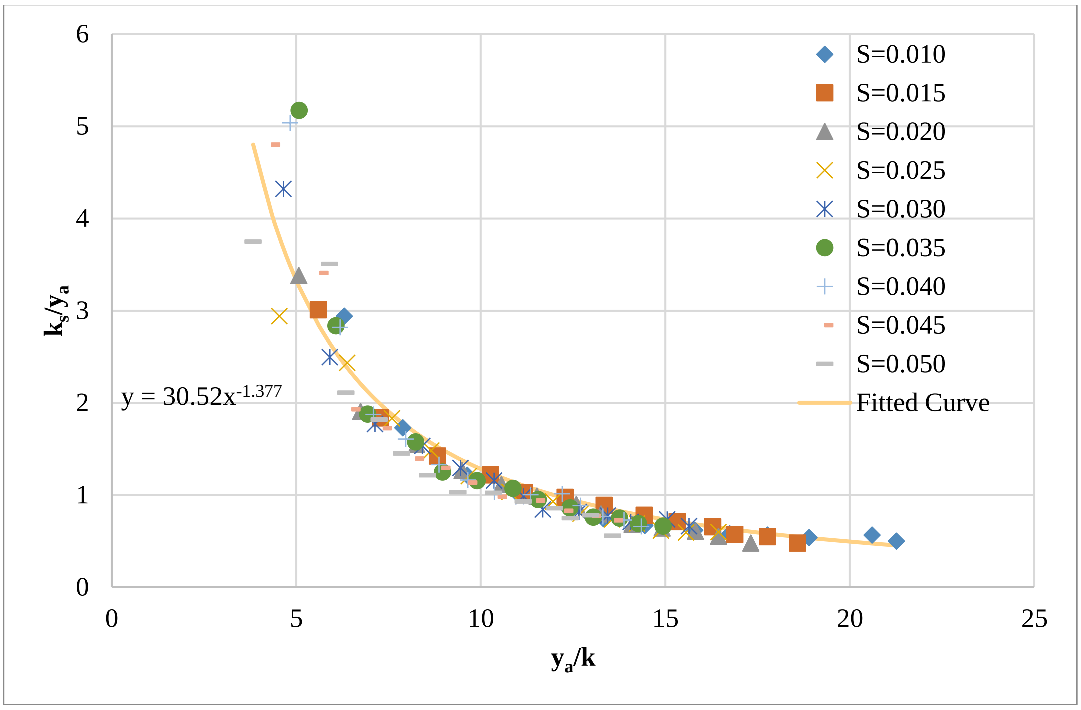

Figure 4.7 Curve Fitted y_a/k vs k_s/y_a for R2 (p/k=16)

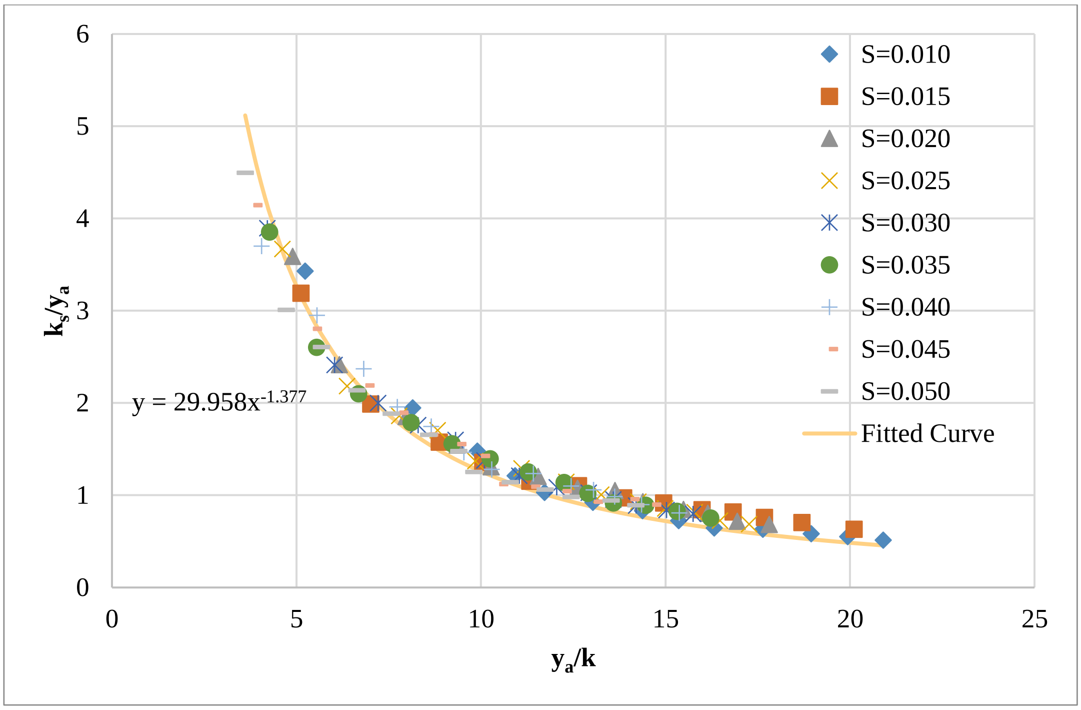

Figure 4.8 Curve Fitted y_a/k vs k_s/y_a for R3 (p/k=8)

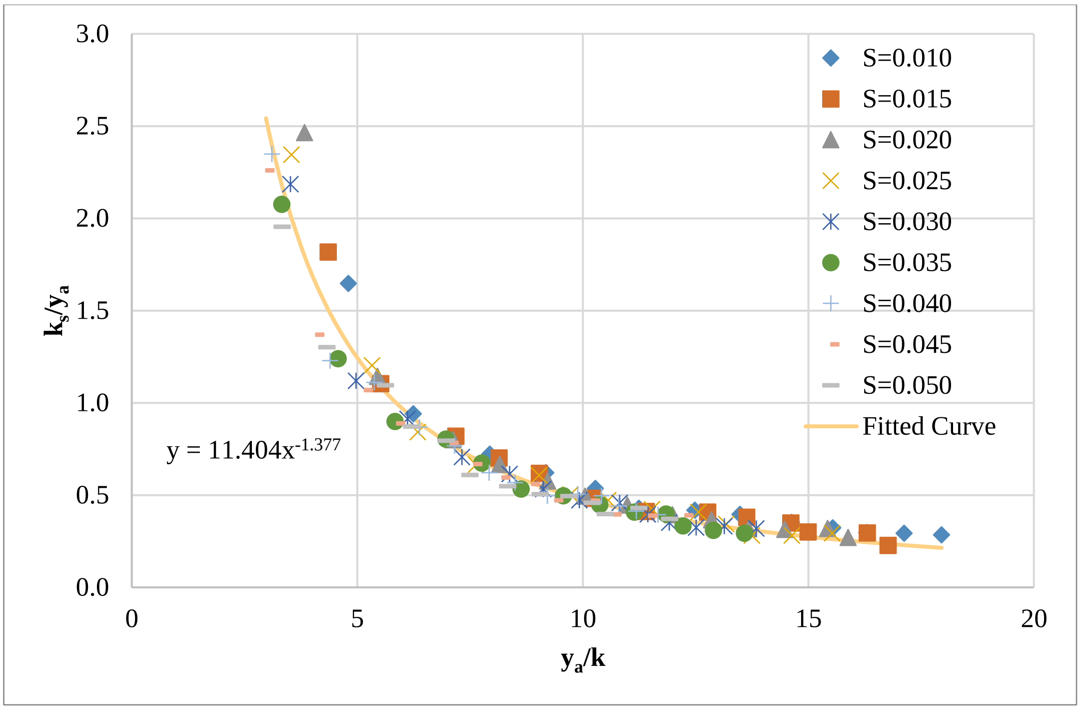

Figure 4.9 Curve Fitted y_a/k vs k_s/y_a for R4 (p/k=4)

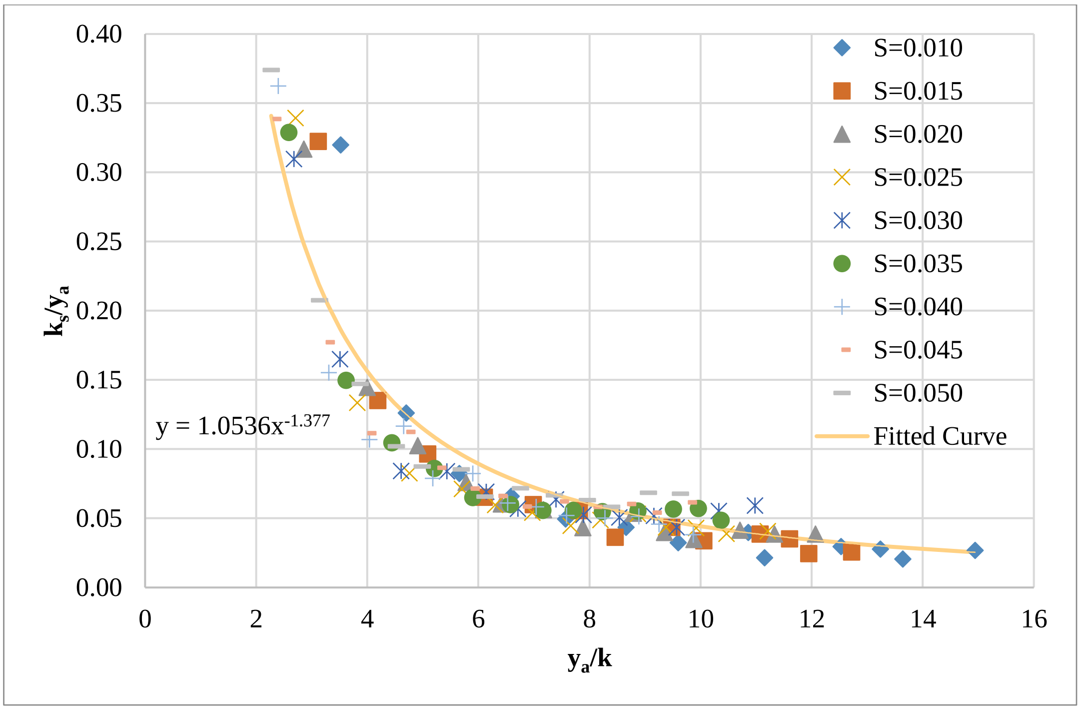

Figure 4.10 Curve Fitted y_a/k vs k_s/y_a for R5 (p/k=2)

As can be seen from the above graphs, Fig. 4.6 to Fig. 4.10, a fitted curve which represents all the points in each roughness pattern was drawn, and corresponding R^2 values were calculated.

Another critical point is how power functions were created. In the optimization stage, power function, $y=ax^b$, is used for curve fit. A standard exponent "b" value was investigated to understand the results better. Using a programming language, trial-and-error methodology has been applied for different "a" and "b" values to get highest R^2 value. "b" was found as -1.3766. The coefficient "a" value in the power function was optimized to get the highest R^2 value for each case. R^2 value shows how well the data fit the regression model, a goodness-of-fit measure. The best-fit results are summarized in Table 4.1.

Table 4.1 Fitted-Curve Equations and R^2 Values for each Roughness Pattern

Roughness Pattern Number	Coefficient "a"	Power "b"	Open Form	R^2 Value
R1	20.3902	-1.3766	$y=20.3902*x^{-1.3766}$	0.9720
R2	30.5204	-1.3766	$y=30.5204*x^{-1.3766}$	0.9588
R3	29.9581	-1.3766	$y=29.9581*x^{-1.3766}$	0.9889
R4	11.4041	-1.3766	$y=11.4041*x^{-1.3766}$	0.9830
R5	1.0536	-1.3766	$y=1.0536*x^{-1.3766}$	0.9509

In the equations given on figures x represents y_a/k dimensionless ratio and y represents k_s/y_a dimensionless ratio.

4.3 Interpretation of Results

y_a/k vs k_s/y_a graphs for each roughness pattern was drawn. Their best-fit curve functions were created to have common sense in the understanding of the behavior of roughness patterns.

The graph of best-fit functions for all roughness patterns is shown in Fig. 4.11:

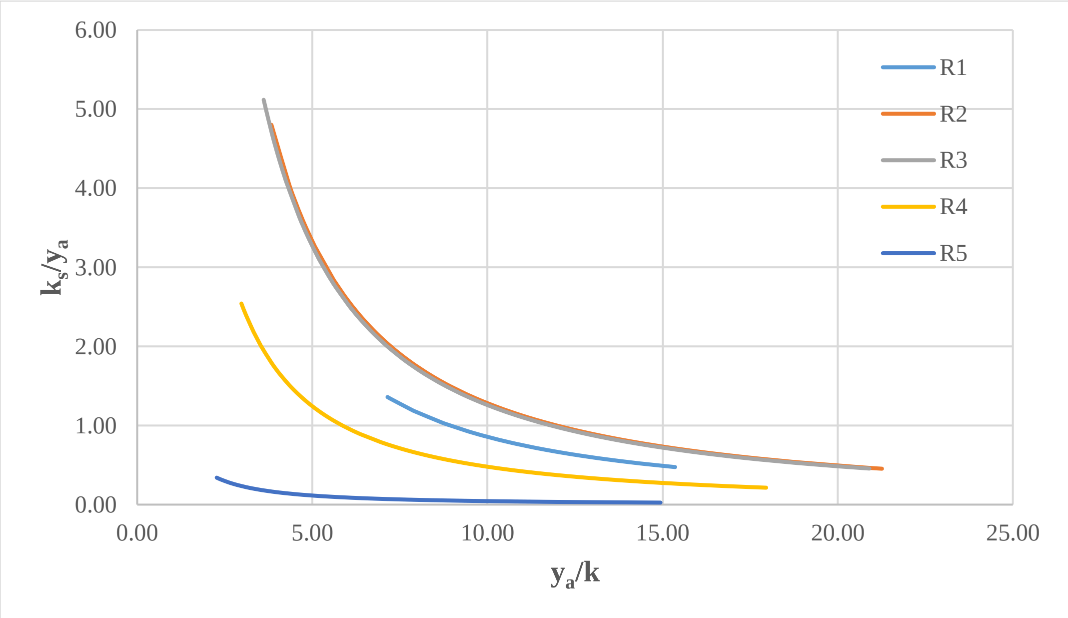

Figure 4.11 Combined Graph of All Roughness Patterns

R2 and R3 almost overlapped because of the constant “a” found after optimization.

Their “a” values are very close to each other. This graph illustrates variation of constant “a” in all test cases.

Fig. 4.11 shows a relationship between rib roughness spacing and relative roughness value. This spacing can be called pitch distance, *p*.

When pitch distance decreases, drag force increases. Thus, roughness increases to a limit value.

This study found that after p/k=16, the surface roughness value starts decreasing with respect to the decreasing pitch distance.

This can be seen from the constant “a” difference. All the fitted curves have the same power “b”; however, their behaviour is controlled by this constant “a”.

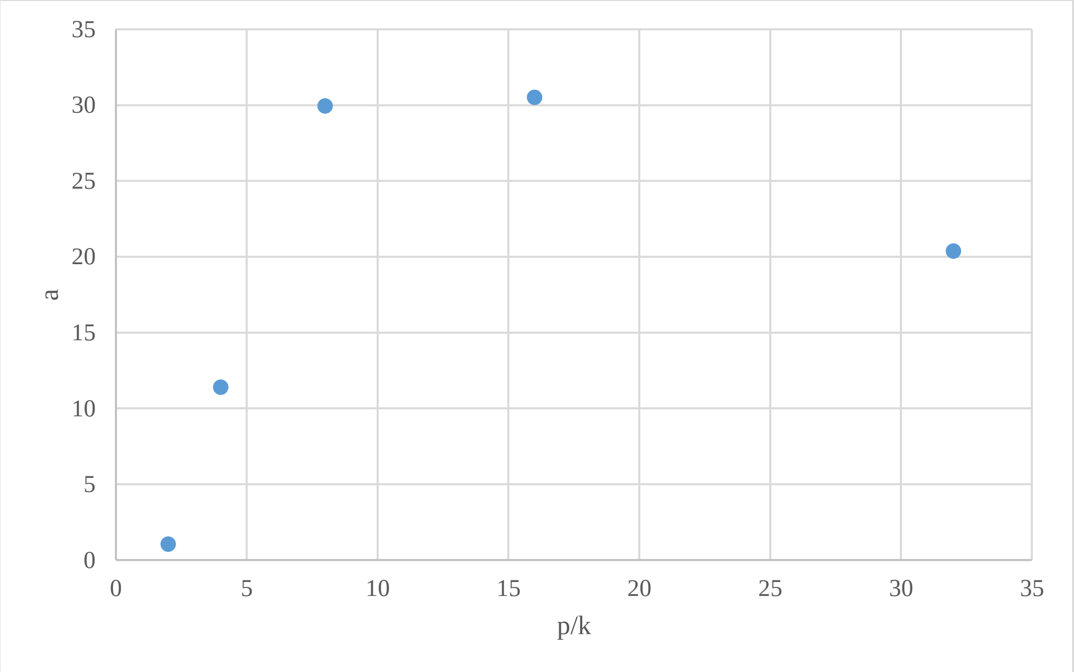

Figure 4.12 p/k vs a Graph

This graph shows why surface roughness value deviation occurs.

At the maximum p/k ratio, ribs were placed sparsely. At the minimum p/k ratio, ribs were placed densely. Secondary flows and disturbances in streamlines are negligible in minimum p/k ratio. Thus, this pattern behaves as a new surface, and the surface roughness value at R5 was the smallest among all patterns.

As mentioned, the power function is used to accomplish a curve-fitting optimization procedure. This procedure's main goal was to have a standard power "b" value. This is because of the standardisation of the general formula for this pitch-to-rib height ratio.

CHAPTER 5

CONCLUSIONS

Laboratory experiments are conducted to investigate the effect of spacing between lateral square bars on the channel bed resistance. Five different spacing between bars are investigated. Water surface profile measurements for different bed slopes and discharges are done. The bed shear stress on the roughened surface is evaluated from measured data. Manning roughness, n and Nikuradse's equivalent roughness height, k_s, are determined. The major conclusions of this study are given below:

1) It is shown that a dimensionless relationship between relative roughness (k_s/y_a) and relative depth (y_a/k) exists for each roughness pattern.
2) It is shown that the relationship between relative roughness and relative depth can be expressed in terms of a power function for each roughness pattern.
3) The best-fit study has shown that the exponent "b" of the power function is common to all roughness patterns.
4) The coefficient "a" of the power function is shown to be a function of dimensionless pitch ratio (p/k).
5) When the coefficient "a" is plotted against the pitch ratio (p/k), the maximum value of the coefficient is expected in the range of $8 \leq p/k \leq 16$.
6) More than the data of this study is needed to provide the functional relationship between the coefficient of the power function and pitch ratio. Some additional experiments with different bar spacing are required to precisely locate the point of the maximum value of 'a'. Then the functional relationship can be better formed.

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APPENDICES

A. All Calculation Tables

Table 5.1 R1 Slope=0.030

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.041	0.0301	0.080	0.080	7.95	0.86	0.0628	18.50
0.051	0.0296	0.089	0.088	8.84	0.96	0.0683	20.10
0.062	0.0297	0.095	0.094	9.44	1.10	0.0718	21.12
0.074	0.0298	0.104	0.103	10.35	1.19	0.0769	22.64
0.088	0.0301	0.114	0.113	11.32	1.30	0.0822	24.19
0.102	0.0299	0.124	0.123	12.34	1.38	0.0874	25.73
0.116	0.0302	0.134	0.133	13.34	1.45	0.0923	27.18
0.131	0.0296	0.143	0.143	14.27	1.53	0.0967	28.46

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00296	1.82	0.14	14.04	13.75	22.92	0.15
0.00331	2.22	0.20	15.62	15.22	25.37	0.16
0.00402	2.83	0.27	16.66	16.13	26.88	0.16
0.00434	3.28	0.34	18.27	17.59	29.31	0.17
0.00470	3.79	0.43	19.99	19.13	31.89	0.18
0.00489	4.19	0.52	21.79	20.76	34.59	0.19
0.00503	4.56	0.61	23.56	22.34	37.23	0.19
0.00527	5.00	0.71	25.20	23.78	39.63	0.20

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.080	0.973	7.260	0.1184	0.0319	0.0355	216071
0.088	1.032	7.185	0.1083	0.0299	0.0336	262589
0.094	1.138	7.051	0.0833	0.0272	0.0307	314437
0.103	1.183	6.994	0.0779	0.0262	0.0298	366836
0.113	1.229	6.936	0.0724	0.0253	0.0291	425928
0.123	1.252	6.907	0.0716	0.0247	0.0287	481808
0.133	1.267	6.889	0.0720	0.0245	0.0287	535302
0.143	1.293	6.856	0.0694	0.0237	0.0279	591783

Table 5.2 R1 Slope=0.035

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.070	0.0347	0.098	0.098	9.78	1.19	0.0738	25.32
0.082	0.0351	0.107	0.107	10.68	1.28	0.0787	27.04
0.093	0.0343	0.116	0.116	11.56	1.34	0.0835	28.66
0.106	0.0349	0.125	0.124	12.43	1.42	0.0879	30.18
0.117	0.0348	0.131	0.131	13.08	1.49	0.0911	31.27
0.129	0.0348	0.138	0.138	13.78	1.56	0.0944	32.42
0.140	0.0347	0.145	0.145	14.49	1.61	0.0977	33.54
0.155	0.0353	0.154	0.154	15.36	1.68	0.1016	34.88

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00460	3.33	0.33	20.15	19.50	32.49	0.18
0.00485	3.75	0.40	22.00	21.20	35.33	0.19
0.00492	4.03	0.47	23.82	22.89	38.15	0.20
0.00516	4.45	0.55	25.62	24.51	40.85	0.20
0.00543	4.85	0.63	26.94	25.67	42.79	0.21
0.00566	5.25	0.72	28.38	26.94	44.89	0.21
0.00577	5.53	0.80	29.84	28.24	47.07	0.22
0.00597	5.95	0.91	31.64	29.81	49.68	0.22

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.098	1.218	6.950	0.0842	0.0275	0.0311	351940
0.107	1.251	6.909	0.0819	0.0269	0.0307	403171
0.116	1.258	6.899	0.0847	0.0264	0.0304	447497
0.124	1.286	6.864	0.0823	0.0260	0.0302	499593
0.131	1.316	6.827	0.0782	0.0253	0.0296	543201
0.138	1.342	6.794	0.0751	0.0248	0.0292	589351
0.145	1.351	6.784	0.0756	0.0245	0.0291	629404
0.154	1.370	6.760	0.0741	0.0243	0.0290	683459

Table 5.3 R1 Slope=0.040

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.044	0.0404	0.072	0.072	7.22	1.02	0.0582	22.84
0.062	0.0394	0.087	0.087	8.68	1.19	0.0673	26.42
0.074	0.0400	0.095	0.096	9.56	1.29	0.0725	28.44
0.086	0.0400	0.103	0.103	10.30	1.39	0.0767	30.09
0.095	0.0402	0.108	0.109	10.86	1.46	0.0797	31.29
0.106	0.0393	0.117	0.118	11.77	1.50	0.0845	33.17
0.117	0.0399	0.123	0.124	12.38	1.58	0.0876	34.39
0.130	0.0397	0.131	0.131	13.09	1.65	0.0912	35.77

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00457	2.61	0.19	17.00	16.62	27.71	0.17
0.00517	3.42	0.30	20.44	19.85	33.08	0.18
0.00551	3.92	0.37	22.50	21.75	36.26	0.19
0.00594	4.47	0.46	24.25	23.33	38.88	0.20
0.00619	4.84	0.53	25.57	24.52	40.86	0.20
0.00607	5.03	0.59	27.71	26.53	44.22	0.21
0.00638	5.48	0.68	29.14	27.79	46.31	0.22
0.00667	5.97	0.78	30.83	29.27	48.78	0.22

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.072	1.207	6.964	0.0822	0.0297	0.0327	236426
0.087	1.290	6.860	0.0764	0.0276	0.0309	320563
0.096	1.333	6.807	0.0734	0.0269	0.0304	374134
0.103	1.384	6.742	0.0676	0.0259	0.0295	426799
0.109	1.413	6.707	0.0651	0.0255	0.0291	465002
0.118	1.397	6.727	0.0717	0.0254	0.0294	507523
0.124	1.430	6.686	0.0680	0.0250	0.0290	552167
0.131	1.460	6.649	0.0650	0.0244	0.0285	603325

Table 5.4 R1 Slope=0.045

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.071	0.0453	0.099	0.098	9.83	1.20	0.0740	32.68
0.084	0.0447	0.108	0.108	10.76	1.30	0.0792	34.96
0.095	0.0452	0.114	0.114	11.39	1.39	0.0826	36.45
0.105	0.0447	0.120	0.120	12.02	1.46	0.0858	37.88
0.116	0.0452	0.126	0.126	12.60	1.53	0.0887	39.17
0.126	0.0452	0.131	0.131	13.11	1.60	0.0912	40.26
0.136	0.0452	0.138	0.138	13.77	1.65	0.0944	41.66
0.148	0.0451	0.143	0.143	14.30	1.72	0.0969	42.75

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00466	3.39	0.33	26.03	25.37	42.28	0.21
0.00498	3.87	0.42	28.50	27.67	46.11	0.21
0.00537	4.35	0.50	30.17	29.18	48.63	0.22
0.00560	4.72	0.57	31.83	30.69	51.16	0.23
0.00595	5.18	0.65	33.37	32.07	53.44	0.23
0.00625	5.60	0.73	34.71	33.24	55.41	0.24
0.00631	5.84	0.80	36.46	34.86	58.09	0.24
0.00669	6.35	0.91	37.88	36.07	60.11	0.25

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.098	1.226	6.940	0.1143	0.0312	0.0355	356529
0.108	1.267	6.889	0.1104	0.0300	0.0344	412174
0.114	1.315	6.829	0.1019	0.0290	0.0335	459037
0.120	1.341	6.796	0.0990	0.0282	0.0328	499804
0.126	1.380	6.747	0.0927	0.0276	0.0322	544614
0.131	1.413	6.706	0.0876	0.0269	0.0315	584619
0.138	1.417	6.702	0.0896	0.0268	0.0316	621473
0.143	1.456	6.653	0.0831	0.0260	0.0308	668134

Table 5.5 R1 Slope=0.050

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.044	0.0498	0.072	0.071	7.15	1.03	0.0577	28.31
0.056	0.0498	0.079	0.078	7.84	1.19	0.0622	30.48
0.070	0.0490	0.095	0.094	9.43	1.24	0.0717	35.19
0.084	0.0500	0.098	0.098	9.81	1.43	0.0739	36.26
0.100	0.0496	0.109	0.108	10.82	1.54	0.0795	39.00
0.112	0.0501	0.115	0.115	11.49	1.62	0.0831	40.75
0.123	0.0502	0.123	0.122	12.23	1.68	0.0869	42.62
0.133	0.0501	0.127	0.127	12.67	1.75	0.0891	43.70

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00472	2.67	0.19	21.03	20.65	34.42	0.19
0.00576	3.51	0.28	23.07	22.52	37.53	0.19
0.00514	3.61	0.34	27.75	27.07	45.11	0.21
0.00657	4.76	0.47	28.86	27.93	46.55	0.22
0.00694	5.41	0.59	31.84	30.67	51.12	0.23
0.00728	5.93	0.68	33.82	32.45	54.09	0.23
0.00730	6.22	0.76	35.99	34.47	57.45	0.24
0.00769	6.72	0.85	37.30	35.59	59.32	0.24

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.071	1.225	6.941	0.1015	0.0325	0.0358	236897
0.078	1.358	6.775	0.0800	0.0294	0.0326	295991
0.094	1.287	6.864	0.1087	0.0309	0.0350	355069
0.098	1.455	6.654	0.0751	0.0276	0.0313	422026
0.108	1.495	6.605	0.0732	0.0267	0.0306	489956
0.115	1.530	6.562	0.0701	0.0262	0.0302	539883
0.122	1.530	6.562	0.0731	0.0262	0.0304	582524
0.127	1.569	6.515	0.0682	0.0255	0.0297	623352

Table 5.6 R2 Slope=0.010

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.014	0.0100	0.064	0.063	6.30	0.370	0.0521	5.11
0.024	0.0100	0.080	0.079	7.89	0.507	0.0625	6.13
0.036	0.0100	0.097	0.096	9.64	0.623	0.0729	7.16
0.046	0.0105	0.111	0.110	11.00	0.697	0.0805	7.90
0.056	0.0100	0.124	0.123	12.29	0.759	0.0872	8.55
0.066	0.0100	0.134	0.133	13.33	0.825	0.0923	9.05
0.076	0.0100	0.145	0.144	14.45	0.877	0.0975	9.57
0.088	0.0100	0.159	0.158	15.80	0.928	0.1035	10.15
0.097	0.0100	0.168	0.167	16.74	0.966	0.1075	10.54
0.106	0.0100	0.178	0.178	17.77	0.994	0.1116	10.95
0.117	0.0100	0.190	0.189	18.90	1.032	0.1159	11.37
0.130	0.0100	0.207	0.206	20.61	1.051	0.1222	11.98
0.140	0.0100	0.213	0.213	21.26	1.097	0.1244	12.21

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00070	0.36	0.02	3.71	3.66	6.11	0.08
0.00104	0.63	0.05	4.65	4.55	7.58	0.09
0.00127	0.91	0.09	5.67	5.50	9.16	0.10
0.00140	1.10	0.12	6.47	6.23	10.39	0.10
0.00149	1.28	0.16	7.24	6.92	11.54	0.11
0.00163	1.48	0.20	7.84	7.45	12.42	0.11
0.00171	1.64	0.24	8.50	8.03	13.38	0.12
0.00177	1.80	0.28	9.30	8.73	14.55	0.12
0.00183	1.92	0.32	9.85	9.21	15.35	0.12
0.00184	2.01	0.36	10.46	9.74	16.24	0.13
0.00188	2.14	0.40	11.12	10.31	17.19	0.13
0.00182	2.19	0.45	12.13	11.23	18.71	0.14
0.00194	2.37	0.50	12.52	11.51	19.18	0.14

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.06	0.47	7.91	0.1854	0.0377	0.0412	77130
0.08	0.58	7.77	0.1363	0.0311	0.0345	126674
0.10	0.64	7.69	0.1172	0.0280	0.0317	181646
0.11	0.67	7.65	0.1113	0.0274	0.0315	224393
0.12	0.69	7.62	0.1088	0.0259	0.0301	264822
0.13	0.72	7.58	0.0990	0.0247	0.0290	304656
0.14	0.74	7.56	0.0969	0.0242	0.0286	341976
0.16	0.75	7.55	0.0976	0.0237	0.0284	384300
0.17	0.75	7.54	0.0971	0.0234	0.0282	415040
0.18	0.75	7.54	0.1005	0.0233	0.0284	443816
0.19	0.76	7.54	0.1014	0.0230	0.0283	478552
0.21	0.74	7.56	0.1162	0.0234	0.0293	513758
0.21	0.76	7.53	0.1064	0.0227	0.0285	546208

Table 5.7 R2 Slope=0.015

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.014	0.0150	0.057	0.056	5.60	0.416	0.0472	6.95
0.025	0.0150	0.073	0.073	7.28	0.572	0.0586	8.62
0.036	0.0150	0.089	0.088	8.82	0.680	0.0682	10.03
0.047	0.0153	0.103	0.103	10.27	0.763	0.0765	11.25
0.056	0.0150	0.112	0.112	11.18	0.835	0.0815	11.99
0.065	0.0150	0.124	0.123	12.29	0.882	0.0872	12.83
0.075	0.0150	0.134	0.133	13.34	0.937	0.0924	13.59
0.087	0.0150	0.145	0.144	14.43	1.005	0.0974	14.34
0.097	0.0150	0.154	0.153	15.32	1.055	0.1014	14.92
0.108	0.0150	0.164	0.163	16.29	1.105	0.1056	15.53
0.118	0.0150	0.170	0.169	16.89	1.165	0.1081	15.90
0.128	0.0150	0.178	0.178	17.77	1.200	0.1116	16.42
0.141	0.0150	0.187	0.186	18.59	1.264	0.1148	16.89

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00102	0.47	0.03	4.95	4.89	8.16	0.09
0.00144	0.83	0.06	6.43	6.31	10.52	0.10
0.00166	1.11	0.10	7.79	7.59	12.66	0.11
0.00179	1.35	0.14	9.06	8.79	14.65	0.12
0.00197	1.58	0.18	9.87	9.52	15.87	0.13
0.00201	1.72	0.21	10.85	10.43	17.38	0.13
0.00210	1.90	0.25	11.78	11.27	18.79	0.14
0.00225	2.15	0.31	12.74	12.12	20.20	0.14
0.00235	2.34	0.36	13.53	12.81	21.35	0.15
0.00245	2.54	0.41	14.38	13.55	22.59	0.15
0.00264	2.79	0.47	14.91	13.97	23.28	0.15
0.00268	2.94	0.52	15.69	14.65	24.41	0.16
0.00287	3.23	0.60	16.41	15.21	25.35	0.16

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.06	0.56	7.79	0.1685	0.0384	0.0416	78646
0.07	0.68	7.64	0.1338	0.0323	0.0357	134111
0.09	0.73	7.57	0.1256	0.0301	0.0338	185459
0.10	0.76	7.53	0.1250	0.0292	0.0333	233450
0.11	0.80	7.49	0.1149	0.0276	0.0317	271960
0.12	0.80	7.48	0.1196	0.0273	0.0318	307419
0.13	0.82	7.46	0.1185	0.0267	0.0314	346081
0.14	0.84	7.42	0.1124	0.0258	0.0306	391605
0.15	0.86	7.40	0.1091	0.0252	0.0302	428043
0.16	0.87	7.39	0.1070	0.0248	0.0299	466649
0.17	0.90	7.35	0.0964	0.0239	0.0289	503332
0.18	0.91	7.34	0.0974	0.0237	0.0288	535873
0.19	0.94	7.31	0.0891	0.0229	0.0280	580396

Table 5.8 R2 Slope=0.020

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0200	0.051	0.051	5.07	0.427	0.0434	8.51
0.025	0.0200	0.068	0.067	6.74	0.618	0.0551	10.80
0.036	0.0200	0.083	0.083	8.26	0.726	0.0648	12.71
0.047	0.0198	0.096	0.095	9.49	0.825	0.0721	14.15
0.057	0.0200	0.106	0.106	10.56	0.899	0.0781	15.33
0.067	0.0200	0.116	0.115	11.53	0.969	0.0833	16.34
0.078	0.0200	0.127	0.126	12.59	1.033	0.0887	17.40
0.087	0.0200	0.133	0.133	13.26	1.094	0.0919	18.04
0.099	0.0200	0.142	0.141	14.10	1.170	0.0959	18.82
0.109	0.0200	0.150	0.149	14.92	1.218	0.0996	19.55
0.120	0.0200	0.159	0.158	15.82	1.264	0.1036	20.32
0.130	0.0200	0.165	0.164	16.44	1.318	0.1062	20.84
0.145	0.0200	0.174	0.173	17.32	1.395	0.1098	21.55

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00120	0.51	0.03	5.97	5.92	9.87	0.10
0.00182	0.98	0.07	7.94	7.80	13.01	0.11
0.00203	1.29	0.11	9.73	9.51	15.86	0.13
0.00227	1.61	0.15	11.17	10.87	18.11	0.13
0.00242	1.86	0.20	12.43	12.04	20.07	0.14
0.00258	2.11	0.24	13.57	13.08	21.81	0.15
0.00270	2.35	0.30	14.82	14.23	23.71	0.15
0.00288	2.60	0.34	15.61	14.92	24.86	0.16
0.00312	2.94	0.41	16.60	15.77	26.28	0.16
0.00321	3.14	0.47	17.56	16.62	27.71	0.17
0.00329	3.34	0.53	18.62	17.56	29.27	0.17
0.00345	3.60	0.59	19.36	18.17	30.29	0.17
0.00370	3.99	0.69	20.39	19.01	31.68	0.18

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.61	7.73	0.1715	0.0409	0.0440	74132
0.07	0.76	7.53	0.1284	0.0331	0.0363	136082
0.08	0.81	7.47	0.1283	0.0314	0.0351	188174
0.09	0.86	7.41	0.1203	0.0295	0.0334	238029
0.11	0.88	7.37	0.1178	0.0287	0.0329	281048
0.12	0.91	7.34	0.1138	0.0278	0.0322	322678
0.13	0.93	7.32	0.1132	0.0272	0.0318	366305
0.13	0.96	7.28	0.1054	0.0263	0.0309	402242
0.14	1.00	7.23	0.0964	0.0253	0.0299	449005
0.15	1.01	7.22	0.0958	0.0250	0.0297	485334
0.16	1.02	7.21	0.0962	0.0247	0.0296	523817
0.16	1.04	7.18	0.0907	0.0241	0.0290	559832
0.17	1.07	7.14	0.0829	0.0232	0.0282	612816

Table 5.9 R2 Slope=0.025

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0250	0.046	0.045	4.54	0.478	0.0394	9.67
0.023	0.0250	0.064	0.064	6.38	0.601	0.0526	12.91
0.033	0.0250	0.077	0.076	7.59	0.724	0.0606	14.86
0.043	0.0249	0.087	0.087	8.66	0.827	0.0672	16.48
0.054	0.0250	0.097	0.097	9.68	0.930	0.0732	17.95
0.066	0.0250	0.108	0.108	10.78	1.021	0.0793	19.45
0.079	0.0250	0.120	0.120	11.96	1.101	0.0855	20.97
0.090	0.0250	0.128	0.127	12.71	1.180	0.0893	21.89
0.101	0.0250	0.136	0.136	13.56	1.241	0.0934	22.91
0.110	0.0250	0.143	0.142	14.23	1.288	0.0965	23.67
0.121	0.0250	0.149	0.149	14.88	1.355	0.0995	24.40
0.130	0.0250	0.156	0.156	15.57	1.392	0.1025	25.14
0.140	0.0250	0.165	0.164	16.44	1.419	0.1062	26.05

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00170	0.66	0.03	6.68	6.62	11.03	0.11
0.00183	0.94	0.06	9.39	9.27	15.45	0.12
0.00221	1.31	0.10	11.17	10.97	18.29	0.14
0.00251	1.65	0.14	12.75	12.46	20.77	0.14
0.00283	2.03	0.20	14.24	13.85	23.08	0.15
0.00306	2.38	0.26	15.86	15.35	25.58	0.16
0.00322	2.70	0.32	17.60	16.95	28.25	0.17
0.00349	3.06	0.39	18.70	17.92	29.87	0.17
0.00364	3.33	0.45	19.96	19.05	31.76	0.18
0.00375	3.55	0.51	20.94	19.93	33.22	0.18
0.00398	3.89	0.58	21.90	20.74	34.57	0.19
0.00404	4.06	0.63	22.91	21.64	36.07	0.19
0.00400	4.17	0.69	24.20	22.82	38.04	0.20

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.72	7.59	0.1333	0.0383	0.0410	75280
0.06	0.76	7.53	0.1553	0.0370	0.0405	126434
0.08	0.84	7.43	0.1391	0.0337	0.0374	175567
0.09	0.90	7.36	0.1283	0.0315	0.0354	222444
0.10	0.95	7.28	0.1165	0.0297	0.0337	272195
0.11	0.99	7.24	0.1116	0.0286	0.0328	323708
0.12	1.02	7.20	0.1111	0.0279	0.0323	376572
0.13	1.06	7.15	0.1016	0.0268	0.0313	421472
0.14	1.08	7.13	0.0998	0.0262	0.0309	463702
0.14	1.09	7.11	0.0983	0.0258	0.0306	497372
0.15	1.12	7.07	0.0912	0.0251	0.0298	539186
0.16	1.13	7.07	0.0923	0.0249	0.0298	570582
0.16	1.12	7.08	0.0981	0.0250	0.0302	602896

Table 5.10 R2 Slope=0.030

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0300	0.047	0.047	4.66	0.429	0.0403	11.86
0.022	0.0300	0.060	0.059	5.91	0.620	0.0494	14.54
0.033	0.0300	0.072	0.071	7.13	0.771	0.0576	16.96
0.044	0.0300	0.085	0.084	8.42	0.871	0.0657	19.35
0.055	0.0300	0.095	0.095	9.45	0.970	0.0719	21.15
0.065	0.0300	0.104	0.104	10.36	1.046	0.0770	22.66
0.076	0.0300	0.112	0.112	11.16	1.135	0.0814	23.94
0.085	0.0300	0.117	0.117	11.68	1.213	0.0841	24.75
0.096	0.0300	0.127	0.127	12.66	1.264	0.0890	26.20
0.106	0.0300	0.135	0.134	13.44	1.314	0.0928	27.32
0.116	0.0300	0.141	0.141	14.06	1.375	0.0957	28.18
0.126	0.0300	0.151	0.151	15.05	1.395	0.1002	29.50
0.137	0.0300	0.157	0.156	15.64	1.460	0.1028	30.26

S_{smooth}	$\tau_{w,\ smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w,\ bed}$ (Pa)	u_* (m/s)
0.00133	0.53	0.02	8.22	8.18	13.63	0.12
0.00212	1.03	0.06	10.44	10.32	17.20	0.13
0.00267	1.51	0.11	12.59	12.38	20.63	0.14
0.00286	1.84	0.16	14.86	14.55	24.26	0.16
0.00315	2.22	0.21	16.69	16.27	27.12	0.16
0.00334	2.52	0.26	18.29	17.77	29.61	0.17
0.00365	2.92	0.33	19.71	19.06	31.77	0.18
0.00399	3.29	0.38	20.63	19.86	33.10	0.18
0.00402	3.51	0.44	22.35	21.46	35.77	0.19
0.00411	3.74	0.50	23.74	22.73	37.88	0.19
0.00432	4.05	0.57	24.83	23.69	39.49	0.20
0.00418	4.11	0.62	26.58	25.34	42.24	0.21
0.00442	4.46	0.70	27.62	26.23	43.71	0.21

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.64	7.69	0.2013	0.0474	0.0508	69249
0.06	0.81	7.46	0.1476	0.0376	0.0409	122520
0.07	0.92	7.33	0.1262	0.0335	0.0370	177742
0.08	0.96	7.28	0.1291	0.0324	0.0363	229059
0.09	1.01	7.22	0.1223	0.0309	0.0350	278816
0.10	1.04	7.18	0.1196	0.0300	0.0343	322121
0.11	1.08	7.12	0.1099	0.0287	0.0330	369268
0.12	1.13	7.06	0.0984	0.0274	0.0317	407845
0.13	1.13	7.06	0.1033	0.0273	0.0319	450097
0.13	1.14	7.04	0.1043	0.0270	0.0318	488001
0.14	1.17	7.01	0.0993	0.0264	0.0312	526525
0.15	1.15	7.04	0.1108	0.0268	0.0321	559347
0.16	1.18	7.00	0.1036	0.0260	0.0313	600318

Table 5.11 R2 Slope=0.035

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0350	0.051	0.051	5.08	0.427	0.0434	14.91
0.023	0.0350	0.061	0.061	6.07	0.631	0.0505	17.34
0.033	0.0350	0.070	0.069	6.93	0.793	0.0563	19.33
0.045	0.0348	0.083	0.082	8.24	0.911	0.0646	22.19
0.055	0.0350	0.090	0.090	8.96	1.023	0.0690	23.69
0.065	0.0350	0.100	0.099	9.90	1.094	0.0745	25.56
0.076	0.0350	0.109	0.109	10.88	1.164	0.0798	27.41
0.086	0.0350	0.116	0.116	11.56	1.240	0.0834	28.65
0.098	0.0350	0.125	0.124	12.42	1.315	0.0878	30.15
0.109	0.0350	0.131	0.130	13.05	1.392	0.0909	31.22
0.118	0.0350	0.138	0.138	13.76	1.429	0.0943	32.39
0.127	0.0350	0.143	0.143	14.27	1.483	0.0967	33.21
0.137	0.0350	0.150	0.149	14.94	1.528	0.0997	34.25

S_{smooth}	$\tau_{w,smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w,bed}$ (Pa)	u_* (m/s)
0.00119	0.51	0.03	10.46	10.41	17.35	0.13
0.00213	1.06	0.06	12.51	12.38	20.64	0.14
0.00292	1.61	0.11	14.28	14.06	23.43	0.15
0.00320	2.03	0.17	16.97	16.64	27.73	0.17
0.00370	2.50	0.22	18.46	18.02	30.03	0.17
0.00382	2.79	0.28	20.40	19.85	33.08	0.18
0.00394	3.09	0.34	22.41	21.74	36.23	0.19
0.00422	3.45	0.40	23.81	23.01	38.35	0.20
0.00443	3.82	0.47	25.58	24.63	41.05	0.20
0.00474	4.23	0.55	26.88	25.78	42.96	0.21
0.00475	4.40	0.61	28.35	27.14	45.23	0.21
0.00495	4.70	0.67	29.40	28.06	46.77	0.22
0.00505	4.94	0.74	30.78	29.31	48.84	0.22

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.60	7.73	0.2626	0.0542	0.0584	74122
0.06	0.82	7.46	0.1723	0.0405	0.0442	127521
0.07	0.96	7.27	0.1301	0.0346	0.0381	178704
0.08	1.01	7.21	0.1298	0.0330	0.0369	235374
0.09	1.09	7.11	0.1119	0.0308	0.0346	282323
0.10	1.11	7.09	0.1143	0.0303	0.0344	325794
0.11	1.13	7.06	0.1166	0.0298	0.0342	371843
0.12	1.16	7.02	0.1097	0.0288	0.0333	413884
0.12	1.19	6.98	0.1069	0.0281	0.0328	462073
0.13	1.23	6.93	0.0992	0.0272	0.0319	506417
0.14	1.23	6.94	0.1029	0.0271	0.0321	539274
0.14	1.25	6.91	0.0986	0.0266	0.0315	573720
0.15	1.26	6.89	0.0990	0.0263	0.0314	609668

Table 5.12 R2 Slope=0.040

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0400	0.049	0.048	4.83	0.448	0.0416	16.33
0.025	0.0400	0.062	0.062	6.19	0.673	0.0513	20.13
0.036	0.0400	0.072	0.071	7.09	0.846	0.0574	22.51
0.045	0.0399	0.080	0.080	7.97	0.941	0.0630	24.71
0.056	0.0400	0.089	0.089	8.87	1.053	0.0684	26.86
0.066	0.0400	0.097	0.096	9.65	1.140	0.0730	28.65
0.076	0.0400	0.104	0.104	10.37	1.221	0.0771	30.24
0.087	0.0400	0.114	0.113	11.35	1.278	0.0823	32.31
0.096	0.0400	0.123	0.122	12.21	1.311	0.0868	34.05
0.106	0.0400	0.128	0.127	12.71	1.390	0.0893	35.03
0.118	0.0400	0.134	0.133	13.31	1.477	0.0922	36.18
0.127	0.0400	0.139	0.139	13.88	1.525	0.0949	37.24
0.137	0.0400	0.144	0.144	14.35	1.591	0.0971	38.09

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00139	0.57	0.03	11.38	11.32	18.87	0.14
0.00238	1.20	0.07	14.57	14.42	24.03	0.16
0.00323	1.82	0.13	16.70	16.44	27.40	0.17
0.00354	2.18	0.17	18.76	18.42	30.69	0.18
0.00396	2.66	0.24	20.88	20.41	34.01	0.18
0.00426	3.05	0.29	22.71	22.13	36.88	0.19
0.00455	3.44	0.36	24.42	23.71	39.51	0.20
0.00456	3.68	0.42	26.72	25.88	43.13	0.21
0.00447	3.81	0.46	28.74	27.81	46.35	0.22
0.00484	4.24	0.54	29.92	28.84	48.07	0.22
0.00524	4.74	0.63	31.34	30.08	50.14	0.22
0.00537	5.00	0.69	32.68	31.30	52.16	0.23
0.00567	5.40	0.78	33.79	32.24	53.73	0.23

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.65	7.67	0.2434	0.0536	0.0576	74643
0.06	0.86	7.40	0.1744	0.0410	0.0448	138169
0.07	1.01	7.21	0.1329	0.0352	0.0388	194109
0.08	1.06	7.14	0.1280	0.0336	0.0374	237032
0.09	1.13	7.06	0.1178	0.0318	0.0358	288158
0.10	1.17	7.01	0.1121	0.0306	0.0348	332934
0.10	1.21	6.96	0.1069	0.0297	0.0339	376494
0.11	1.21	6.96	0.1137	0.0296	0.0342	420824
0.12	1.20	6.98	0.1238	0.0299	0.0349	454895
0.13	1.25	6.92	0.1124	0.0287	0.0337	496400
0.13	1.29	6.86	0.1023	0.0276	0.0325	544877
0.14	1.31	6.84	0.1013	0.0273	0.0323	578818
0.14	1.34	6.80	0.0945	0.0266	0.0315	617778

Table 5.13 R2 Slope=0.045

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0450	0.044	0.043	4.33	0.462	0.0379	16.71
0.021	0.0450	0.057	0.056	5.64	0.620	0.0475	20.97
0.033	0.0450	0.066	0.065	6.51	0.845	0.0535	23.61
0.041	0.0446	0.074	0.074	7.36	0.929	0.0591	26.08
0.052	0.0450	0.083	0.082	8.24	1.052	0.0646	28.53
0.060	0.0450	0.090	0.089	8.95	1.118	0.0689	30.42
0.070	0.0450	0.097	0.097	9.68	1.206	0.0732	32.30
0.082	0.0450	0.105	0.105	10.47	1.305	0.0776	34.27
0.095	0.0450	0.116	0.115	11.52	1.375	0.0832	36.74
0.108	0.0450	0.123	0.123	12.28	1.465	0.0871	38.47
0.120	0.0450	0.131	0.130	13.04	1.534	0.0909	40.12
0.130	0.0450	0.137	0.136	13.63	1.590	0.0937	41.37

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00168	0.62	0.03	11.48	11.42	19.04	0.14
0.00224	1.04	0.06	14.95	14.83	24.71	0.16
0.00355	1.86	0.12	17.24	16.99	28.32	0.17
0.00375	2.17	0.16	19.49	19.17	31.94	0.18
0.00427	2.71	0.22	21.82	21.37	35.62	0.19
0.00442	2.99	0.27	23.70	23.16	38.61	0.20
0.00475	3.41	0.33	25.63	24.97	41.62	0.20
0.00514	3.92	0.41	27.74	26.92	44.86	0.21
0.00520	4.25	0.49	30.51	29.53	49.21	0.22
0.00556	4.75	0.58	32.53	31.37	52.28	0.23
0.00576	5.13	0.67	34.53	33.19	55.32	0.24
0.00594	5.46	0.74	36.10	34.61	57.68	0.24

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.71	7.60	0.2080	0.0518	0.0553	69905
0.06	0.83	7.44	0.1923	0.0448	0.0487	117837
0.07	1.06	7.15	0.1255	0.0356	0.0390	180785
0.07	1.09	7.11	0.1270	0.0345	0.0382	219504
0.08	1.17	7.01	0.1148	0.0325	0.0363	271984
0.09	1.19	6.98	0.1157	0.0319	0.0359	308107
0.10	1.24	6.93	0.1099	0.0308	0.0349	352845
0.10	1.29	6.86	0.1028	0.0296	0.0338	405213
0.12	1.29	6.86	0.1084	0.0294	0.0340	457638
0.12	1.34	6.80	0.1020	0.0285	0.0332	510850
0.13	1.36	6.78	0.1006	0.0280	0.0328	557653
0.14	1.38	6.75	0.0989	0.0275	0.0325	595954

Table 5.14 R2 Slope=0.050

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0500	0.039	0.038	3.83	0.522	0.0340	16.67
0.023	0.0500	0.060	0.059	5.90	0.649	0.0493	24.19
0.032	0.0500	0.064	0.063	6.34	0.841	0.0524	25.68
0.041	0.0497	0.073	0.072	7.24	0.943	0.0584	28.62
0.050	0.0500	0.079	0.079	7.86	1.061	0.0623	30.54
0.060	0.0500	0.086	0.086	8.56	1.169	0.0666	32.66
0.072	0.0500	0.094	0.094	9.38	1.280	0.0714	35.04
0.083	0.0500	0.104	0.103	10.35	1.337	0.0769	37.74
0.095	0.0500	0.112	0.111	11.15	1.420	0.0813	39.87
0.108	0.0500	0.121	0.120	12.00	1.500	0.0857	42.04
0.118	0.0500	0.125	0.124	12.42	1.583	0.0878	43.09
0.124	0.0500	0.130	0.130	12.98	1.592	0.0906	44.45
0.139	0.0500	0.136	0.136	13.57	1.707	0.0934	41.25

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00247	0.82	0.03	11.28	11.22	18.69	0.14
0.00233	1.13	0.07	17.37	17.24	28.73	0.17
0.00361	1.85	0.12	18.67	18.43	30.72	0.18
0.00393	2.25	0.16	21.32	20.99	34.99	0.19
0.00456	2.78	0.22	23.12	22.69	37.81	0.19
0.00506	3.31	0.28	25.18	24.62	41.03	0.20
0.00552	3.87	0.36	27.60	26.87	44.79	0.21
0.00546	4.12	0.43	30.45	29.60	49.33	0.22
0.00573	4.57	0.51	32.81	31.79	52.98	0.23
0.00596	5.01	0.60	35.31	34.11	56.84	0.24
0.00642	5.53	0.69	36.56	35.19	58.64	0.24
0.00623	5.53	0.72	38.21	36.77	61.28	0.25
0.00687	6.30	0.85	35.95	34.24	57.07	0.24

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.85	7.42	0.1436	0.0450	0.0476	70938
0.06	0.85	7.41	0.2070	0.0463	0.0505	128125
0.06	1.07	7.14	0.1339	0.0372	0.0407	176102
0.07	1.12	7.08	0.1317	0.0356	0.0393	220167
0.08	1.21	6.96	0.1139	0.0331	0.0369	264148
0.09	1.28	6.88	0.1038	0.0314	0.0352	311223
0.09	1.33	6.80	0.0968	0.0301	0.0340	365691
0.10	1.33	6.81	0.1058	0.0303	0.0346	411426
0.11	1.36	6.77	0.1035	0.0295	0.0341	461753
0.12	1.38	6.74	0.1027	0.0290	0.0337	514316
0.12	1.43	6.68	0.0930	0.0279	0.0326	556309
0.13	1.41	6.71	0.1013	0.0283	0.0333	576979
0.14	1.48	6.62	0.0759	0.0270	0.0318	638017

Table 5.15 R3 Slope=0.010

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0100	0.054	0.052	5.23	0.318	0.0446	4.37
0.024	0.0100	0.083	0.082	8.15	0.491	0.0641	6.29
0.035	0.0100	0.100	0.099	9.90	0.589	0.0745	7.30
0.043	0.0100	0.111	0.109	10.93	0.656	0.0801	7.86
0.050	0.0108	0.118	0.117	11.72	0.711	0.0843	8.27
0.060	0.0100	0.132	0.130	13.03	0.767	0.0908	8.91
0.071	0.0100	0.145	0.144	14.38	0.823	0.0972	9.54
0.081	0.0100	0.155	0.154	15.36	0.879	0.1016	9.96
0.091	0.0100	0.165	0.163	16.33	0.929	0.1057	10.37
0.102	0.0100	0.178	0.176	17.64	0.964	0.1111	10.90
0.115	0.0100	0.191	0.190	18.95	1.011	0.1161	11.39
0.125	0.0100	0.201	0.199	19.94	1.045	0.1198	11.75
0.136	0.0100	0.210	0.209	20.91	1.084	0.1232	12.09

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00064	0.28	0.01	3.08	3.05	5.09	0.07
0.00094	0.59	0.05	4.80	4.70	7.83	0.09
0.00111	0.81	0.08	5.83	5.67	9.45	0.10
0.00125	0.98	0.11	6.43	6.22	10.36	0.10
0.00137	1.13	0.13	6.90	6.63	11.06	0.11
0.00144	1.29	0.17	7.67	7.33	12.22	0.11
0.00152	1.44	0.21	8.46	8.05	13.41	0.12
0.00163	1.63	0.25	9.04	8.54	14.23	0.12
0.00173	1.79	0.29	9.61	9.02	15.04	0.12
0.00174	1.90	0.33	10.38	9.71	16.19	0.13
0.00181	2.06	0.39	11.15	10.37	17.29	0.13
0.00185	2.17	0.43	11.74	10.87	18.12	0.13
0.00192	2.32	0.48	12.30	11.34	18.89	0.14

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.44	7.94	0.1795	0.0395	0.0426	56762
0.08	0.55	7.81	0.1585	0.0326	0.0364	125819
0.10	0.60	7.74	0.1462	0.0301	0.0342	175417
0.11	0.63	7.70	0.1322	0.0283	0.0325	210141
0.12	0.66	7.66	0.1206	0.0281	0.0325	239693
0.13	0.68	7.64	0.1201	0.0263	0.0308	278875
0.14	0.69	7.62	0.1195	0.0257	0.0305	319964
0.15	0.72	7.59	0.1109	0.0248	0.0296	357182
0.16	0.73	7.57	0.1053	0.0241	0.0290	392876
0.18	0.73	7.57	0.1108	0.0240	0.0292	428212
0.19	0.74	7.56	0.1100	0.0235	0.0290	469867
0.20	0.75	7.55	0.1100	0.0233	0.0289	500601
0.21	0.76	7.54	0.1070	0.0228	0.0286	534329

Table 5.16 R3 Slope=0.015

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0150	0.052	0.051	5.12	0.390	0.0438	6.44
0.023	0.0150	0.071	0.070	7.01	0.546	0.0569	8.37
0.035	0.0150	0.090	0.089	8.87	0.658	0.0685	10.07
0.044	0.0150	0.102	0.101	10.05	0.730	0.0753	11.08
0.055	0.0152	0.115	0.113	11.33	0.809	0.0822	12.10
0.065	0.0150	0.128	0.126	12.64	0.857	0.0889	13.09
0.077	0.0150	0.140	0.139	13.87	0.926	0.0948	13.95
0.087	0.0150	0.151	0.150	14.95	0.970	0.0998	14.68
0.098	0.0150	0.161	0.160	16.00	1.021	0.1043	15.35
0.106	0.0150	0.170	0.168	16.83	1.050	0.1078	15.87
0.116	0.0150	0.178	0.177	17.68	1.094	0.1112	16.37
0.128	0.0150	0.188	0.187	18.70	1.141	0.1152	16.95
0.146	0.0150	0.202	0.201	20.11	1.210	0.1204	17.72

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00099	0.42	0.02	4.52	4.48	7.47	0.09
0.00137	0.76	0.05	6.19	6.09	10.14	0.10
0.00154	1.04	0.09	7.83	7.65	12.75	0.11
0.00168	1.24	0.12	8.87	8.62	14.37	0.12
0.00183	1.48	0.17	10.00	9.67	16.11	0.13
0.00185	1.61	0.20	11.16	10.75	17.92	0.13
0.00198	1.84	0.26	12.24	11.73	19.55	0.14
0.00203	1.99	0.30	13.20	12.60	21.01	0.14
0.00212	2.17	0.35	14.12	13.43	22.38	0.15
0.00215	2.27	0.38	14.86	14.09	23.49	0.15
0.00224	2.44	0.43	15.61	14.75	24.58	0.16
0.00232	2.63	0.49	16.51	15.52	25.87	0.16
0.00246	2.91	0.58	17.76	16.59	27.64	0.17

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.55	7.80	0.1634	0.0390	0.0420	68327
0.07	0.66	7.66	0.1393	0.0331	0.0365	124274
0.09	0.71	7.60	0.1396	0.0312	0.0351	180087
0.10	0.73	7.57	0.1361	0.0299	0.0341	219725
0.11	0.77	7.52	0.1302	0.0288	0.0332	266170
0.13	0.77	7.52	0.1392	0.0285	0.0333	304878
0.14	0.79	7.49	0.1344	0.0275	0.0326	351077
0.15	0.80	7.48	0.1368	0.0272	0.0325	387097
0.16	0.82	7.46	0.1346	0.0266	0.0321	426133
0.17	0.82	7.46	0.1377	0.0264	0.0322	452701
0.18	0.83	7.44	0.1342	0.0259	0.0317	486577
0.19	0.84	7.43	0.1316	0.0254	0.0314	525721
0.20	0.86	7.40	0.1266	0.0247	0.0308	582718

Table 5.17 R3 Slope=0.020

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0200	0.050	0.049	4.90	0.409	0.0421	8.26
0.020	0.0200	0.063	0.062	6.17	0.541	0.0511	10.03
0.032	0.0200	0.081	0.080	7.97	0.670	0.0629	12.35
0.043	0.0200	0.095	0.094	9.36	0.766	0.0713	13.99
0.052	0.0196	0.104	0.103	10.28	0.843	0.0765	15.02
0.063	0.0200	0.117	0.116	11.55	0.909	0.0834	16.36
0.074	0.0200	0.127	0.126	12.62	0.977	0.0888	17.43
0.083	0.0200	0.138	0.136	13.64	1.015	0.0937	18.39
0.093	0.0200	0.145	0.144	14.39	1.077	0.0973	19.08
0.106	0.0200	0.156	0.155	15.49	1.141	0.1022	20.04
0.114	0.0200	0.163	0.161	16.15	1.177	0.1050	20.59
0.126	0.0200	0.171	0.170	16.95	1.239	0.1083	21.25
0.137	0.0200	0.179	0.178	17.81	1.282	0.1118	21.93

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00114	0.47	0.02	5.76	5.72	9.53	0.10
0.00154	0.77	0.05	7.26	7.16	11.94	0.11
0.00179	1.11	0.09	9.38	9.20	15.33	0.12
0.00198	1.39	0.13	11.01	10.75	17.92	0.13
0.00219	1.64	0.17	12.10	11.76	19.60	0.14
0.00227	1.86	0.21	13.60	13.17	21.95	0.15
0.00241	2.10	0.27	14.86	14.33	23.88	0.15
0.00242	2.22	0.30	16.05	15.44	25.74	0.16
0.00259	2.48	0.36	16.94	16.23	27.05	0.16
0.00272	2.73	0.42	18.23	17.39	28.98	0.17
0.00280	2.88	0.47	19.01	18.08	30.13	0.17
0.00297	3.16	0.54	19.95	18.88	31.47	0.18
0.00305	3.35	0.60	20.97	19.77	32.96	0.18

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.59	7.75	0.1756	0.0419	0.0450	68778
0.06	0.70	7.62	0.1489	0.0360	0.0393	110604
0.08	0.76	7.54	0.1476	0.0334	0.0372	168576
0.09	0.80	7.48	0.1443	0.0317	0.0359	218524
0.10	0.84	7.43	0.1343	0.0299	0.0342	258225
0.12	0.85	7.41	0.1390	0.0297	0.0344	303249
0.13	0.88	7.38	0.1356	0.0288	0.0337	347255
0.14	0.88	7.38	0.1433	0.0288	0.0340	380429
0.14	0.91	7.35	0.1337	0.0278	0.0331	419013
0.15	0.93	7.32	0.1310	0.0271	0.0326	466036
0.16	0.94	7.31	0.1297	0.0267	0.0323	494095
0.17	0.96	7.28	0.1217	0.0259	0.0316	536741
0.18	0.97	7.26	0.1212	0.0256	0.0314	573102

Table 5.18 R3 Slope=0.025

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0250	0.047	0.046	4.62	0.433	0.0400	9.82
0.024	0.0250	0.065	0.064	6.37	0.628	0.0525	12.89
0.034	0.0250	0.079	0.078	7.79	0.728	0.0618	15.16
0.042	0.0249	0.090	0.088	8.83	0.793	0.0682	16.73
0.053	0.0250	0.100	0.099	9.85	0.896	0.0742	18.19
0.064	0.0250	0.112	0.111	11.10	0.961	0.0810	19.87
0.077	0.0250	0.124	0.123	12.32	1.042	0.0873	21.41
0.089	0.0250	0.134	0.133	13.26	1.119	0.0920	22.55
0.101	0.0250	0.144	0.143	14.27	1.180	0.0967	23.71
0.111	0.0250	0.151	0.150	14.99	1.234	0.1000	24.51
0.121	0.0250	0.159	0.158	15.79	1.277	0.1035	25.37
0.133	0.0250	0.166	0.165	16.48	1.345	0.1064	26.09
0.144	0.0250	0.174	0.173	17.27	1.390	0.1096	26.88

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00137	0.54	0.02	6.80	6.75	11.25	0.11
0.00200	1.03	0.07	9.37	9.24	15.40	0.12
0.00217	1.31	0.10	11.46	11.25	18.75	0.14
0.00225	1.51	0.13	12.99	12.73	21.21	0.15
0.00258	1.88	0.18	14.50	14.13	23.55	0.15
0.00263	2.09	0.23	16.33	15.87	26.45	0.16
0.00280	2.40	0.30	18.12	17.53	29.22	0.17
0.00301	2.72	0.36	19.51	18.79	31.32	0.18
0.00314	2.98	0.42	20.99	20.14	33.57	0.18
0.00328	3.22	0.48	22.06	21.09	35.15	0.19
0.00336	3.41	0.54	23.23	22.16	36.93	0.19
0.00359	3.75	0.62	24.25	23.02	38.36	0.20
0.00368	3.96	0.68	25.41	24.04	40.06	0.20

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.64	7.68	0.1694	0.0427	0.0457	69324
0.06	0.79	7.49	0.1390	0.0353	0.0386	131977
0.08	0.83	7.44	0.1447	0.0340	0.0378	179966
0.09	0.85	7.42	0.1503	0.0332	0.0374	216328
0.10	0.91	7.34	0.1351	0.0311	0.0354	265971
0.11	0.92	7.33	0.1430	0.0308	0.0355	311436
0.12	0.95	7.29	0.1409	0.0299	0.0349	363937
0.13	0.98	7.25	0.1334	0.0288	0.0339	411466
0.14	1.00	7.23	0.1326	0.0282	0.0336	456342
0.15	1.02	7.20	0.1282	0.0276	0.0330	493443
0.16	1.03	7.19	0.1288	0.0273	0.0329	528500
0.16	1.06	7.15	0.1192	0.0264	0.0320	572289
0.17	1.07	7.14	0.1185	0.0260	0.0318	609330

Table 5.19 R3 Slope=0.030

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.011	0.0300	0.043	0.042	4.22	0.435	0.0370	10.88
0.023	0.0300	0.062	0.060	6.04	0.635	0.0502	14.79
0.032	0.0300	0.073	0.072	7.22	0.739	0.0582	17.12
0.041	0.0300	0.084	0.083	8.30	0.823	0.0650	19.13
0.050	0.0300	0.094	0.093	9.32	0.895	0.0711	20.92
0.059	0.0300	0.102	0.101	10.09	0.975	0.0755	22.22
0.070	0.0300	0.112	0.110	11.04	1.057	0.0807	23.75
0.082	0.0300	0.122	0.121	12.05	1.134	0.0860	25.30
0.092	0.0300	0.130	0.129	12.92	1.187	0.0903	26.58
0.101	0.0300	0.137	0.136	13.59	1.239	0.0935	27.52
0.110	0.0300	0.143	0.142	14.21	1.291	0.0964	28.37
0.121	0.0300	0.152	0.150	15.03	1.342	0.1001	29.47
0.131	0.0300	0.159	0.157	15.75	1.387	0.1033	30.39

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00154	0.56	0.02	7.44	7.40	12.33	0.11
0.00218	1.07	0.06	10.66	10.53	17.55	0.13
0.00242	1.38	0.10	12.74	12.54	20.90	0.14
0.00259	1.65	0.14	14.66	14.38	23.97	0.15
0.00272	1.90	0.18	16.45	16.10	26.83	0.16
0.00298	2.20	0.22	17.82	17.37	28.95	0.17
0.00320	2.54	0.28	19.49	18.93	31.56	0.18
0.00339	2.86	0.34	21.28	20.59	34.31	0.19
0.00348	3.08	0.40	22.81	22.02	36.70	0.19
0.00362	3.32	0.45	23.99	23.09	38.48	0.20
0.00377	3.56	0.51	25.08	24.07	40.12	0.20
0.00387	3.80	0.57	26.54	25.40	42.33	0.21
0.00397	4.02	0.63	27.80	26.54	44.23	0.21

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.68	7.64	0.1642	0.0442	0.0470	64299
0.06	0.83	7.45	0.1454	0.0371	0.0404	127654
0.07	0.88	7.38	0.1442	0.0352	0.0389	171974
0.08	0.91	7.34	0.1460	0.0340	0.0381	214099
0.09	0.94	7.31	0.1488	0.0332	0.0376	254356
0.10	0.98	7.25	0.1390	0.0317	0.0362	294338
0.11	1.02	7.21	0.1335	0.0306	0.0353	341131
0.12	1.04	7.17	0.1308	0.0297	0.0346	390012
0.13	1.05	7.16	0.1327	0.0294	0.0345	428705
0.14	1.07	7.13	0.1296	0.0288	0.0341	463462
0.14	1.09	7.11	0.1258	0.0282	0.0336	497681
0.15	1.10	7.09	0.1259	0.0278	0.0334	537419
0.16	1.12	7.08	0.1254	0.0275	0.0332	572740

Table 5.20 R3 Slope=0.035

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0350	0.044	0.043	4.27	0.468	0.0374	12.83
0.021	0.0350	0.057	0.055	5.54	0.631	0.0468	16.07
0.030	0.0350	0.068	0.067	6.69	0.748	0.0547	18.77
0.042	0.0348	0.082	0.081	8.11	0.863	0.0638	21.92
0.053	0.0350	0.093	0.092	9.22	0.958	0.0705	24.21
0.064	0.0350	0.104	0.103	10.25	1.041	0.0764	26.23
0.076	0.0350	0.114	0.113	11.28	1.123	0.0820	28.15
0.088	0.0350	0.124	0.123	12.25	1.197	0.0870	29.87
0.098	0.0350	0.130	0.129	12.90	1.267	0.0902	30.97
0.109	0.0350	0.137	0.136	13.59	1.337	0.0935	32.11
0.120	0.0350	0.146	0.145	14.47	1.383	0.0976	33.51
0.133	0.0352	0.154	0.153	15.32	1.447	0.1014	34.81
0.148	0.0353	0.164	0.162	16.23	1.520	0.1053	36.16

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00176	0.64	0.03	8.80	8.74	14.57	0.12
0.00236	1.08	0.06	11.42	11.30	18.84	0.14
0.00270	1.45	0.10	13.77	13.58	22.63	0.15
0.00292	1.83	0.15	16.71	16.41	27.35	0.17
0.00315	2.18	0.20	18.99	18.59	30.99	0.18
0.00334	2.50	0.26	21.12	20.60	34.34	0.19
0.00354	2.85	0.32	23.24	22.60	37.66	0.19
0.00372	3.17	0.39	25.24	24.46	40.76	0.20
0.00397	3.51	0.45	26.56	25.66	42.77	0.21
0.00421	3.87	0.53	27.99	26.94	44.89	0.21
0.00425	4.07	0.59	29.80	28.62	47.70	0.22
0.00443	4.41	0.67	31.55	30.20	50.34	0.22
0.00465	4.80	0.78	33.43	31.87	53.11	0.23

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.72	7.58	0.1645	0.0447	0.0476	70032
0.06	0.86	7.41	0.1443	0.0385	0.0417	118160
0.07	0.92	7.32	0.1402	0.0360	0.0396	163555
0.08	0.97	7.27	0.1450	0.0345	0.0386	220415
0.09	1.01	7.22	0.1435	0.0333	0.0377	270270
0.10	1.04	7.18	0.1428	0.0324	0.0370	318012
0.11	1.07	7.14	0.1410	0.0314	0.0364	368217
0.12	1.09	7.11	0.1395	0.0307	0.0358	416568
0.13	1.13	7.07	0.1315	0.0297	0.0349	456930
0.14	1.16	7.03	0.1244	0.0288	0.0341	500172
0.14	1.16	7.02	0.1287	0.0287	0.0342	539750
0.15	1.18	7.00	0.1262	0.0282	0.0339	586989
0.16	1.20	6.97	0.1221	0.0276	0.0334	640339

Table 5.21 R3 Slope=0.040

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0400	0.042	0.041	4.06	0.493	0.0357	14.02
0.021	0.0400	0.057	0.056	5.56	0.630	0.0469	18.39
0.031	0.0400	0.070	0.068	6.83	0.757	0.0556	21.82
0.040	0.0400	0.079	0.077	7.73	0.862	0.0615	24.12
0.049	0.0400	0.088	0.087	8.65	0.944	0.0671	26.35
0.060	0.0400	0.097	0.095	9.54	1.048	0.0724	28.40
0.070	0.0400	0.104	0.103	10.29	1.134	0.0766	30.07
0.082	0.0400	0.115	0.114	11.42	1.197	0.0827	32.46
0.096	0.0400	0.126	0.124	12.44	1.286	0.0879	34.51
0.104	0.0400	0.132	0.131	13.05	1.328	0.0909	35.69
0.113	0.0400	0.138	0.136	13.63	1.382	0.0937	36.77
0.125	0.0402	0.145	0.144	14.36	1.451	0.0971	38.10
0.142	0.0402	0.155	0.154	15.38	1.539	0.1017	39.89

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00207	0.72	0.03	9.55	9.49	15.81	0.13
0.00235	1.08	0.06	13.08	12.96	21.60	0.15
0.00270	1.47	0.10	16.07	15.87	26.45	0.16
0.00307	1.85	0.14	18.20	17.91	29.86	0.17
0.00327	2.15	0.19	20.37	19.99	33.32	0.18
0.00364	2.59	0.25	22.46	21.97	36.61	0.19
0.00395	2.97	0.31	24.23	23.62	39.36	0.20
0.00397	3.22	0.37	26.89	26.15	43.58	0.21
0.00423	3.65	0.45	29.29	28.38	47.30	0.22
0.00431	3.85	0.50	30.72	29.72	49.53	0.22
0.00449	4.13	0.56	32.08	30.95	51.59	0.23
0.00472	4.50	0.65	33.80	32.51	54.18	0.23
0.00499	4.98	0.77	36.20	34.67	57.78	0.24

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.78	7.50	0.1500	0.0440	0.0467	70474
0.06	0.85	7.41	0.1639	0.0413	0.0447	118127
0.07	0.93	7.32	0.1617	0.0385	0.0424	168364
0.08	0.99	7.24	0.1511	0.0361	0.0402	212033
0.09	1.02	7.19	0.1509	0.0350	0.0394	253558
0.10	1.08	7.12	0.1397	0.0331	0.0376	303490
0.10	1.13	7.06	0.1315	0.0318	0.0364	347481
0.11	1.13	7.06	0.1408	0.0317	0.0368	395944
0.12	1.16	7.02	0.1368	0.0307	0.0360	452403
0.13	1.17	7.01	0.1378	0.0305	0.0359	483159
0.14	1.20	6.98	0.1340	0.0298	0.0354	518052
0.14	1.22	6.94	0.1290	0.0292	0.0348	563634
0.15	1.25	6.91	0.1243	0.0284	0.0342	625882

Table 5.22 R3 Slope=0.045

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.011	0.0450	0.040	0.039	3.85	0.476	0.0341	15.06
0.022	0.0450	0.056	0.055	5.47	0.671	0.0462	20.41
0.034	0.0450	0.070	0.069	6.89	0.823	0.0560	24.72
0.043	0.0450	0.079	0.078	7.80	0.919	0.0619	27.33
0.052	0.0450	0.087	0.086	8.61	1.007	0.0669	29.53
0.060	0.0450	0.095	0.094	9.37	1.067	0.0714	31.52
0.068	0.0450	0.101	0.100	10.02	1.132	0.0751	33.15
0.079	0.0450	0.106	0.105	10.51	1.253	0.0778	34.36
0.089	0.0450	0.115	0.114	11.38	1.304	0.0825	36.41
0.100	0.0450	0.124	0.122	12.23	1.363	0.0869	38.35
0.114	0.0450	0.132	0.131	13.08	1.453	0.0911	40.21
0.125	0.0450	0.142	0.141	14.07	1.481	0.0958	42.27
0.135	0.0448	0.148	0.147	14.66	1.535	0.0985	43.47

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00205	0.69	0.03	10.20	10.14	16.91	0.13
0.00271	1.23	0.07	14.48	14.34	23.90	0.15
0.00316	1.74	0.12	18.24	18.00	30.00	0.17
0.00345	2.09	0.16	20.66	20.33	33.89	0.18
0.00373	2.45	0.21	22.81	22.38	37.31	0.19
0.00385	2.69	0.25	24.82	24.31	40.52	0.20
0.00404	2.98	0.30	26.53	25.93	43.22	0.21
0.00472	3.61	0.38	27.84	27.08	45.13	0.21
0.00474	3.83	0.44	30.13	29.26	48.76	0.22
0.00483	4.11	0.50	32.39	31.39	52.31	0.23
0.00515	4.60	0.60	34.64	33.44	55.74	0.24
0.00501	4.70	0.66	37.26	35.93	59.89	0.24
0.00518	5.00	0.73	38.83	37.36	62.27	0.25

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.77	7.51	0.1596	0.0469	0.0497	64993
0.05	0.92	7.33	0.1533	0.0407	0.0441	124066
0.07	1.00	7.22	0.1507	0.0377	0.0416	184357
0.08	1.05	7.16	0.1477	0.0361	0.0402	227513
0.09	1.10	7.10	0.1428	0.0347	0.0390	269360
0.09	1.11	7.08	0.1457	0.0342	0.0388	304801
0.10	1.14	7.05	0.1427	0.0334	0.0381	339873
0.11	1.23	6.93	0.1177	0.0309	0.0354	390027
0.11	1.23	6.93	0.1243	0.0308	0.0357	430211
0.12	1.24	6.92	0.1276	0.0305	0.0357	473597
0.13	1.28	6.87	0.1214	0.0296	0.0348	529248
0.14	1.26	6.90	0.1343	0.0300	0.0357	567331
0.15	1.28	6.87	0.1315	0.0294	0.0352	604568

Table 5.23 R3 Slope=0.050

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0500	0.037	0.036	3.61	0.462	0.0322	15.81
0.018	0.0500	0.048	0.047	4.72	0.636	0.0408	20.00
0.025	0.0500	0.058	0.057	5.68	0.734	0.0477	23.41
0.034	0.0500	0.068	0.066	6.64	0.853	0.0544	26.67
0.043	0.0500	0.077	0.076	7.57	0.947	0.0604	29.63
0.054	0.0500	0.087	0.086	8.58	1.049	0.0667	32.73
0.064	0.0500	0.095	0.094	9.40	1.135	0.0716	35.11
0.072	0.0500	0.099	0.098	9.81	1.224	0.0739	36.25
0.085	0.0500	0.109	0.108	10.80	1.312	0.0794	38.94
0.098	0.0500	0.119	0.117	11.75	1.391	0.0844	41.40
0.109	0.0500	0.126	0.124	12.45	1.460	0.0880	43.14
0.124	0.0498	0.137	0.135	13.53	1.528	0.0932	45.73
0.135	0.0501	0.143	0.142	14.20	1.585	0.0964	47.27

S_{smooth}	$\tau_{w,\ smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w,\ bed}$ (Pa)	u_* (m/s)
0.00208	0.66	0.02	10.62	10.58	17.63	0.13
0.00288	1.15	0.05	13.89	13.78	22.97	0.15
0.00311	1.46	0.08	16.70	16.54	27.56	0.17
0.00354	1.89	0.13	19.54	19.29	32.15	0.18
0.00379	2.24	0.17	22.26	21.92	36.54	0.19
0.00407	2.66	0.23	25.25	24.79	41.32	0.20
0.00433	3.04	0.29	27.66	27.09	45.15	0.21
0.00483	3.50	0.34	28.86	28.17	46.95	0.22
0.00505	3.93	0.42	31.77	30.92	51.53	0.23
0.00522	4.33	0.51	34.57	33.55	55.92	0.24
0.00545	4.70	0.58	36.63	35.46	59.09	0.24
0.00552	5.05	0.68	39.81	38.45	64.08	0.25
0.00568	5.37	0.76	41.79	40.26	67.11	0.26

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.78	7.51	0.1622	0.0490	0.0518	59506
0.05	0.93	7.31	0.1421	0.0417	0.0447	103687
0.06	0.98	7.25	0.1478	0.0401	0.0435	140154
0.07	1.06	7.15	0.1418	0.0376	0.0413	185590
0.08	1.10	7.10	0.1425	0.0363	0.0404	228937
0.09	1.14	7.04	0.1419	0.0351	0.0394	279938
0.09	1.18	7.00	0.1389	0.0340	0.0385	324873
0.10	1.25	6.91	0.1226	0.0322	0.0366	361764
0.11	1.28	6.88	0.1232	0.0315	0.0362	416718
0.12	1.30	6.85	0.1246	0.0309	0.0360	469517
0.12	1.32	6.82	0.1220	0.0303	0.0355	513606
0.14	1.33	6.81	0.1274	0.0300	0.0356	569748
0.14	1.34	6.79	0.1264	0.0297	0.0354	610867

Table 5.24 R4 Slope=0.010

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0100	0.051	0.048	4.81	0.416	0.0414	4.06
0.021	0.0100	0.065	0.062	6.24	0.561	0.0517	5.07
0.032	0.0100	0.082	0.079	7.94	0.672	0.0628	6.16
0.041	0.0100	0.094	0.092	9.18	0.744	0.0703	6.90
0.050	0.0100	0.105	0.103	10.28	0.811	0.0765	7.51
0.060	0.0098	0.115	0.112	11.24	0.889	0.0818	8.02
0.070	0.0100	0.127	0.125	12.49	0.934	0.0882	8.65
0.079	0.0100	0.137	0.135	13.49	0.976	0.0930	9.13
0.091	0.0100	0.149	0.146	14.63	1.037	0.0983	9.65
0.101	0.0100	0.158	0.155	15.54	1.083	0.1024	10.04
0.110	0.0100	0.165	0.163	16.30	1.125	0.1056	10.36
0.118	0.0100	0.174	0.171	17.12	1.149	0.1090	10.69
0.127	0.0100	0.182	0.180	17.96	1.179	0.1123	11.02

S_{smooth}	$\tau_{w,\ smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w,\ bed}$ (Pa)	u_* (m/s)
0.00121	0.49	0.02	2.83	2.78	4.64	0.07
0.00164	0.83	0.05	3.67	3.57	5.95	0.08
0.00181	1.11	0.09	4.67	4.50	7.49	0.09
0.00191	1.32	0.12	5.40	5.16	8.60	0.09
0.00202	1.52	0.16	6.05	5.74	9.56	0.10
0.00223	1.79	0.20	6.62	6.22	10.36	0.10
0.00223	1.92	0.24	7.35	6.87	11.45	0.11
0.00226	2.06	0.28	7.94	7.38	12.30	0.11
0.00237	2.29	0.33	8.61	7.94	13.23	0.12
0.00245	2.46	0.38	9.15	8.38	13.97	0.12
0.00254	2.63	0.43	9.59	8.74	14.56	0.12
0.00253	2.71	0.46	10.08	9.15	15.25	0.12
0.00256	2.83	0.51	10.57	9.55	15.92	0.13

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.05	0.61	7.73	0.0792	0.0288	0.0307	68956
0.06	0.72	7.59	0.0586	0.0247	0.0268	115894
0.08	0.76	7.53	0.0573	0.0235	0.0259	168687
0.09	0.78	7.50	0.0570	0.0229	0.0256	209290
0.10	0.81	7.47	0.0550	0.0222	0.0251	248293
0.11	0.85	7.42	0.0483	0.0210	0.0238	290958
0.12	0.84	7.42	0.0522	0.0212	0.0244	329528
0.13	0.85	7.42	0.0534	0.0210	0.0244	363344
0.15	0.87	7.40	0.0514	0.0205	0.0241	407843
0.16	0.88	7.38	0.0501	0.0202	0.0238	443566
0.16	0.89	7.37	0.0482	0.0199	0.0235	475213
0.17	0.89	7.37	0.0503	0.0199	0.0237	500849
0.18	0.89	7.37	0.0510	0.0197	0.0237	529663

Table 5.25 R4 Slope=0.015

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0150	0.046	0.044	4.36	0.459	0.0380	5.60
0.020	0.0150	0.058	0.055	5.51	0.604	0.0466	6.86
0.032	0.0150	0.074	0.072	7.19	0.742	0.0580	8.53
0.040	0.0150	0.084	0.081	8.15	0.818	0.0641	9.43
0.048	0.0150	0.093	0.090	9.04	0.885	0.0694	10.22
0.061	0.0148	0.105	0.102	10.23	0.994	0.0763	11.22
0.074	0.0150	0.117	0.114	11.41	1.081	0.0826	12.16
0.087	0.0150	0.130	0.128	12.77	1.136	0.0895	13.18
0.097	0.0150	0.139	0.136	13.63	1.186	0.0937	13.79
0.109	0.0150	0.149	0.146	14.61	1.243	0.0983	14.46
0.117	0.0150	0.152	0.150	15.00	1.300	0.1000	14.71
0.132	0.0150	0.166	0.163	16.31	1.349	0.1056	15.54
0.145	0.0150	0.170	0.168	16.77	1.441	0.1076	15.83

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00165	0.62	0.03	3.85	3.79	6.32	0.08
0.00218	1.00	0.05	4.87	4.76	7.93	0.09
0.00246	1.40	0.10	6.34	6.14	10.24	0.10
0.00261	1.64	0.13	7.19	6.92	11.54	0.11
0.00275	1.87	0.17	7.98	7.64	12.73	0.11
0.00306	2.29	0.23	9.03	8.56	14.27	0.12
0.00325	2.63	0.30	10.07	9.47	15.78	0.13
0.00322	2.83	0.36	11.27	10.55	17.58	0.13
0.00330	3.04	0.41	12.03	11.21	18.68	0.14
0.00341	3.29	0.48	12.90	11.94	19.90	0.14
0.00364	3.57	0.54	13.24	12.17	20.28	0.14
0.00365	3.78	0.62	14.40	13.16	21.94	0.15
0.00406	4.28	0.72	14.81	13.37	22.28	0.15

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.70	7.61	0.0791	0.0302	0.0320	69859
0.06	0.82	7.45	0.0609	0.0262	0.0282	112628
0.07	0.88	7.37	0.0589	0.0247	0.0271	172112
0.08	0.92	7.33	0.0571	0.0240	0.0265	209726
0.09	0.94	7.30	0.0558	0.0234	0.0261	245933
0.10	0.99	7.24	0.0493	0.0220	0.0248	303286
0.11	1.02	7.20	0.0470	0.0215	0.0245	357445
0.13	1.02	7.21	0.0519	0.0216	0.0249	406875
0.14	1.03	7.19	0.0517	0.0213	0.0248	444648
0.15	1.04	7.18	0.0510	0.0210	0.0246	488680
0.15	1.07	7.13	0.0449	0.0203	0.0238	520058
0.16	1.07	7.14	0.0480	0.0203	0.0241	570133
0.17	1.12	7.07	0.0382	0.0192	0.0228	620056

Table 5.26 R4 Slope=0.020

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0200	0.041	0.038	3.83	0.435	0.0340	6.66
0.022	0.0200	0.057	0.055	5.45	0.673	0.0461	9.05
0.036	0.0200	0.074	0.071	7.12	0.843	0.0575	11.29
0.046	0.0200	0.084	0.082	8.15	0.940	0.0641	12.58
0.057	0.0196	0.095	0.092	9.22	1.030	0.0705	13.84
0.067	0.0200	0.103	0.101	10.05	1.111	0.0753	14.77
0.078	0.0200	0.112	0.110	10.99	1.183	0.0804	15.78
0.091	0.0200	0.122	0.120	11.99	1.265	0.0857	16.81
0.102	0.0200	0.131	0.129	12.85	1.323	0.0900	17.65
0.115	0.0200	0.139	0.137	13.68	1.402	0.0939	18.43
0.125	0.0200	0.147	0.145	14.48	1.439	0.0977	19.16
0.136	0.0200	0.157	0.154	15.43	1.469	0.1019	19.99
0.147	0.0200	0.161	0.159	15.89	1.542	0.1039	20.38

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00172	0.57	0.02	4.51	4.46	7.44	0.09
0.00274	1.24	0.07	6.42	6.28	10.47	0.10
0.00320	1.80	0.13	8.38	8.12	13.54	0.12
0.00344	2.17	0.18	9.60	9.25	15.41	0.12
0.00364	2.52	0.23	10.86	10.39	17.32	0.13
0.00388	2.87	0.29	11.83	11.25	18.76	0.14
0.00404	3.18	0.35	12.93	12.23	20.39	0.14
0.00424	3.56	0.43	14.11	13.26	22.10	0.15
0.00434	3.83	0.49	15.13	14.14	23.57	0.15
0.00460	4.24	0.58	16.10	14.94	24.90	0.16
0.00460	4.41	0.64	17.05	15.77	26.28	0.16
0.00454	4.54	0.70	18.16	16.76	27.93	0.17
0.00487	4.96	0.79	18.70	17.12	28.54	0.17

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.71	7.60	0.0944	0.0341	0.0360	59119
0.05	0.92	7.33	0.0623	0.0270	0.0291	124118
0.07	1.01	7.22	0.0569	0.0250	0.0274	193966
0.08	1.05	7.16	0.0544	0.0241	0.0267	241122
0.09	1.08	7.12	0.0532	0.0232	0.0259	290646
0.10	1.12	7.07	0.0497	0.0227	0.0256	334582
0.11	1.14	7.05	0.0489	0.0223	0.0253	380627
0.12	1.17	7.02	0.0471	0.0217	0.0249	433437
0.13	1.18	7.00	0.0471	0.0215	0.0248	476079
0.14	1.21	6.96	0.0435	0.0209	0.0242	526617
0.14	1.21	6.96	0.0454	0.0208	0.0244	562050
0.15	1.19	6.98	0.0493	0.0210	0.0248	598789
0.16	1.24	6.93	0.0430	0.0203	0.0240	640732

Table 5.27 R4 Slope=0.025

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0250	0.038	0.035	3.54	0.471	0.0317	7.77
0.023	0.0250	0.056	0.053	5.33	0.720	0.0452	11.09
0.033	0.0250	0.066	0.063	6.34	0.868	0.0523	12.84
0.046	0.0249	0.079	0.076	7.63	1.005	0.0608	14.92
0.060	0.0250	0.093	0.090	9.03	1.107	0.0694	17.03
0.070	0.0250	0.100	0.097	9.73	1.200	0.0734	18.01
0.080	0.0250	0.108	0.106	10.57	1.262	0.0781	19.16
0.093	0.0250	0.118	0.115	11.53	1.344	0.0833	20.43
0.106	0.0250	0.128	0.126	12.57	1.406	0.0886	21.72
0.118	0.0250	0.134	0.132	13.18	1.492	0.0916	22.46
0.131	0.0250	0.140	0.138	13.75	1.588	0.0943	23.12
0.143	0.0250	0.149	0.146	14.63	1.629	0.0983	24.12
0.154	0.0250	0.158	0.155	15.53	1.653	0.1023	25.10

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00221	0.69	0.02	5.21	5.16	8.60	0.09
0.00322	1.43	0.08	7.84	7.68	12.81	0.11
0.00384	1.97	0.13	9.33	9.08	15.13	0.12
0.00422	2.52	0.19	11.23	10.84	18.07	0.13
0.00430	2.93	0.26	13.29	12.76	21.27	0.15
0.00468	3.37	0.33	14.31	13.65	22.76	0.15
0.00477	3.65	0.39	15.55	14.77	24.62	0.16
0.00497	4.06	0.47	16.97	16.03	26.72	0.16
0.00501	4.35	0.55	18.49	17.40	28.99	0.17
0.00539	4.85	0.64	19.39	18.12	30.19	0.17
0.00588	5.43	0.75	20.23	18.74	31.23	0.18
0.00585	5.64	0.83	21.53	19.88	33.13	0.18
0.00571	5.73	0.89	22.85	21.07	35.12	0.19

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.80	7.48	0.0830	0.0336	0.0354	59630
0.05	1.00	7.23	0.0641	0.0279	0.0300	130219
0.06	1.10	7.10	0.0533	0.0255	0.0277	181618
0.08	1.16	7.02	0.0507	0.0243	0.0267	244486
0.09	1.18	7.00	0.0549	0.0241	0.0270	307432
0.10	1.23	6.94	0.0489	0.0231	0.0260	352423
0.11	1.24	6.92	0.0499	0.0229	0.0260	394429
0.12	1.26	6.89	0.0489	0.0224	0.0257	447869
0.13	1.27	6.89	0.0512	0.0223	0.0258	498062
0.13	1.31	6.83	0.0453	0.0215	0.0250	546549
0.14	1.37	6.76	0.0387	0.0206	0.0240	598857
0.15	1.36	6.77	0.0411	0.0207	0.0242	640825
0.16	1.34	6.80	0.0456	0.0209	0.0248	676477

Table 5.28 R4 Slope=0.030

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.011	0.0300	0.038	0.035	3.52	0.521	0.0315	9.27
0.023	0.0300	0.052	0.050	4.98	0.771	0.0427	12.56
0.033	0.0300	0.064	0.061	6.12	0.899	0.0508	14.95
0.046	0.0300	0.076	0.073	7.32	1.047	0.0588	17.32
0.058	0.0299	0.086	0.084	8.38	1.154	0.0655	19.27
0.068	0.0300	0.094	0.091	9.12	1.242	0.0700	20.59
0.079	0.0300	0.102	0.099	9.92	1.327	0.0745	21.94
0.090	0.0300	0.111	0.108	10.82	1.387	0.0795	23.39
0.101	0.0300	0.117	0.114	11.44	1.471	0.0828	24.37
0.110	0.0300	0.122	0.119	11.92	1.539	0.0853	25.10
0.120	0.0300	0.128	0.125	12.52	1.598	0.0883	25.99
0.128	0.0300	0.134	0.131	13.14	1.624	0.0914	26.89
0.139	0.0300	0.141	0.138	13.85	1.673	0.0947	27.88

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00273	0.84	0.03	6.22	6.16	10.26	0.10
0.00398	1.67	0.08	8.78	8.62	14.37	0.12
0.00430	2.14	0.13	10.80	10.54	17.56	0.13
0.00479	2.77	0.20	12.93	12.52	20.87	0.14
0.00504	3.24	0.27	14.79	14.25	23.75	0.15
0.00535	3.67	0.34	16.11	15.44	25.74	0.16
0.00561	4.11	0.41	17.52	16.70	27.84	0.17
0.00563	4.39	0.47	19.10	18.15	30.25	0.17
0.00600	4.87	0.56	20.20	19.09	31.81	0.18
0.00631	5.28	0.63	21.04	19.78	32.97	0.18
0.00649	5.63	0.70	22.10	20.69	34.48	0.19
0.00641	5.75	0.75	23.19	21.68	36.14	0.19
0.00648	6.03	0.83	24.45	22.78	37.97	0.19

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.89	7.37	0.0769	0.0332	0.0349	65632
0.05	1.10	7.10	0.0557	0.0275	0.0294	131523
0.06	1.16	7.02	0.0558	0.0264	0.0286	182750
0.07	1.24	6.93	0.0517	0.0250	0.0275	246517
0.08	1.27	6.88	0.0514	0.0244	0.0270	302253
0.09	1.31	6.83	0.0486	0.0237	0.0265	347604
0.10	1.35	6.79	0.0468	0.0231	0.0260	395792
0.11	1.35	6.79	0.0494	0.0231	0.0263	441014
0.11	1.39	6.74	0.0452	0.0224	0.0255	487452
0.12	1.42	6.69	0.0418	0.0218	0.0250	524872
0.13	1.44	6.67	0.0407	0.0215	0.0248	564507
0.13	1.43	6.68	0.0434	0.0216	0.0251	593486
0.14	1.44	6.68	0.0441	0.0215	0.0251	634052

Table 5.29 R4 Slope=0.035

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.011	0.0350	0.036	0.033	3.33	0.551	0.0299	10.28
0.021	0.0350	0.048	0.046	4.58	0.765	0.0397	13.63
0.033	0.0350	0.061	0.058	5.84	0.943	0.0488	16.77
0.044	0.0350	0.072	0.070	6.97	1.053	0.0565	19.41
0.054	0.0347	0.080	0.078	7.76	1.160	0.0616	21.17
0.067	0.0350	0.089	0.086	8.64	1.293	0.0671	23.02
0.079	0.0350	0.098	0.096	9.57	1.376	0.0726	24.91
0.091	0.0350	0.106	0.104	10.38	1.461	0.0771	26.48
0.103	0.0350	0.114	0.111	11.15	1.540	0.0813	27.90
0.113	0.0350	0.121	0.118	11.85	1.590	0.0849	29.16
0.123	0.0350	0.125	0.122	12.22	1.678	0.0868	29.81
0.135	0.0350	0.131	0.129	12.90	1.745	0.0902	30.97
0.147	0.0350	0.138	0.136	13.58	1.804	0.0935	32.10

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00327	0.96	0.03	6.85	6.79	11.31	0.11
0.00432	1.68	0.08	9.42	9.27	15.45	0.12
0.00498	2.38	0.14	12.02	11.74	19.57	0.14
0.00511	2.83	0.20	14.35	13.95	23.26	0.15
0.00553	3.34	0.26	15.98	15.46	25.77	0.16
0.00614	4.04	0.35	17.79	17.09	28.49	0.17
0.00626	4.45	0.43	19.72	18.86	31.44	0.18
0.00650	4.92	0.51	21.38	20.36	33.94	0.18
0.00674	5.37	0.60	22.96	21.76	36.27	0.19
0.00677	5.64	0.67	24.40	23.07	38.44	0.20
0.00732	6.23	0.76	25.17	23.65	39.42	0.20
0.00753	6.66	0.86	26.56	24.85	41.41	0.20
0.00767	7.04	0.96	27.98	26.07	43.44	0.21

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	0.97	7.27	0.0690	0.0327	0.0343	66017
0.05	1.14	7.05	0.0567	0.0285	0.0303	121475
0.06	1.25	6.92	0.0524	0.0265	0.0286	184177
0.07	1.27	6.88	0.0560	0.0262	0.0286	238063
0.08	1.33	6.81	0.0522	0.0251	0.0276	286028
0.09	1.41	6.72	0.0459	0.0239	0.0266	346836
0.10	1.42	6.70	0.0474	0.0237	0.0266	399292
0.10	1.45	6.66	0.0464	0.0232	0.0263	450718
0.11	1.47	6.63	0.0454	0.0228	0.0260	500668
0.12	1.47	6.63	0.0470	0.0227	0.0261	540088
0.12	1.53	6.56	0.0407	0.0219	0.0251	582662
0.13	1.55	6.54	0.0399	0.0216	0.0249	629444
0.14	1.56	6.52	0.0398	0.0214	0.0248	674621

Table 5.30 R4 Slope=0.040

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0400	0.034	0.031	3.11	0.537	0.0281	11.04
0.021	0.0400	0.047	0.044	4.40	0.795	0.0384	15.06
0.029	0.0400	0.056	0.054	5.38	0.899	0.0456	17.89
0.040	0.0400	0.066	0.064	6.37	1.046	0.0526	20.63
0.049	0.0400	0.074	0.072	7.16	1.141	0.0578	22.68
0.060	0.0400	0.082	0.079	7.92	1.263	0.0627	24.59
0.068	0.0400	0.087	0.085	8.50	1.333	0.0662	25.99
0.079	0.0400	0.095	0.092	9.22	1.429	0.0705	27.66
0.087	0.0400	0.101	0.099	9.89	1.466	0.0744	29.19
0.094	0.0400	0.107	0.104	10.41	1.505	0.0773	30.33
0.102	0.0400	0.110	0.108	10.80	1.575	0.0794	31.15
0.109	0.0400	0.114	0.112	11.19	1.624	0.0815	31.97
0.117	0.0400	0.119	0.117	11.67	1.672	0.0840	32.96

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00337	0.93	0.03	7.31	7.25	12.09	0.11
0.00489	1.84	0.08	10.36	10.20	17.00	0.13
0.00497	2.22	0.12	12.65	12.42	20.69	0.14
0.00555	2.86	0.18	15.01	14.64	24.41	0.16
0.00582	3.30	0.24	16.86	16.38	27.31	0.17
0.00641	3.94	0.31	18.65	18.02	30.04	0.17
0.00663	4.31	0.37	20.01	19.28	32.13	0.18
0.00701	4.85	0.45	21.70	20.80	34.67	0.19
0.00687	5.01	0.50	23.29	22.29	37.16	0.19
0.00688	5.22	0.54	24.51	23.42	39.04	0.20
0.00727	5.66	0.61	25.42	24.19	40.32	0.20
0.00747	5.97	0.67	26.33	25.00	41.66	0.20
0.00760	6.26	0.73	27.46	26.00	43.34	0.21

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	0.97	7.26	0.0729	0.0345	0.0361	60414
0.04	1.21	6.96	0.0541	0.0286	0.0304	122093
0.05	1.24	6.92	0.0597	0.0284	0.0305	163958
0.06	1.32	6.82	0.0553	0.0268	0.0292	219931
0.07	1.36	6.77	0.0549	0.0262	0.0288	263724
0.08	1.43	6.68	0.0492	0.0250	0.0276	316456
0.08	1.46	6.65	0.0483	0.0246	0.0273	353247
0.09	1.50	6.60	0.0458	0.0239	0.0267	402907
0.10	1.49	6.61	0.0500	0.0241	0.0272	436200
0.10	1.49	6.61	0.0517	0.0241	0.0274	465231
0.11	1.53	6.56	0.0475	0.0235	0.0267	500061
0.11	1.55	6.54	0.0461	0.0231	0.0264	529319
0.12	1.56	6.52	0.0459	0.0229	0.0263	561622

Table 5.31 R4 Slope=0.045

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.010	0.0450	0.032	0.030	2.98	0.560	0.0271	11.95
0.019	0.0450	0.043	0.041	4.08	0.777	0.0359	15.84
0.029	0.0450	0.054	0.052	5.16	0.937	0.0440	19.44
0.037	0.0450	0.061	0.059	5.88	1.050	0.0491	21.69
0.050	0.0450	0.073	0.071	7.06	1.181	0.0571	25.21
0.058	0.0450	0.078	0.076	7.59	1.274	0.0605	26.73
0.067	0.0450	0.085	0.082	8.21	1.360	0.0645	28.46
0.076	0.0450	0.091	0.089	8.86	1.429	0.0684	30.21
0.086	0.0450	0.096	0.094	9.37	1.529	0.0714	31.53
0.097	0.0450	0.104	0.102	10.20	1.586	0.0761	33.59
0.108	0.0450	0.109	0.107	10.67	1.687	0.0787	34.75
0.120	0.0450	0.117	0.115	11.46	1.746	0.0829	36.59
0.132	0.0450	0.125	0.123	12.27	1.794	0.0871	38.43

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00386	1.03	0.03	7.88	7.82	13.03	0.11
0.00510	1.80	0.07	10.79	10.65	17.75	0.13
0.00564	2.44	0.13	13.67	13.42	22.36	0.15
0.00612	2.95	0.17	15.56	15.21	25.36	0.16
0.00634	3.55	0.25	18.69	18.19	30.31	0.17
0.00683	4.06	0.31	20.09	19.47	32.46	0.18
0.00716	4.53	0.37	21.75	21.00	35.00	0.19
0.00729	4.90	0.43	23.48	22.61	37.69	0.19
0.00789	5.53	0.52	24.83	23.80	39.66	0.20
0.00780	5.82	0.59	27.00	25.82	43.03	0.21
0.00844	6.51	0.70	28.26	26.87	44.79	0.21
0.00843	6.86	0.79	30.34	28.77	47.95	0.22
0.00834	7.12	0.87	32.49	30.74	51.23	0.23

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.04	7.18	0.0672	0.0341	0.0356	60652
0.04	1.23	6.94	0.0558	0.0297	0.0314	111519
0.05	1.32	6.83	0.0551	0.0282	0.0303	164960
0.06	1.38	6.74	0.0522	0.0271	0.0293	206272
0.07	1.42	6.70	0.0552	0.0266	0.0292	269869
0.08	1.48	6.63	0.0506	0.0257	0.0283	308634
0.08	1.52	6.58	0.0489	0.0251	0.0278	350694
0.09	1.53	6.56	0.0497	0.0248	0.0277	391097
0.09	1.59	6.48	0.0443	0.0239	0.0268	436825
0.10	1.59	6.49	0.0480	0.0240	0.0272	482647
0.11	1.65	6.42	0.0422	0.0231	0.0262	531104
0.11	1.65	6.42	0.0445	0.0231	0.0264	578941
0.12	1.64	6.43	0.0479	0.0232	0.0268	624630

Table 5.32 R4 Slope=0.050

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0500	0.036	0.033	3.33	0.651	0.0300	14.70
0.022	0.0500	0.046	0.043	4.33	0.847	0.0378	18.56
0.034	0.0500	0.059	0.056	5.63	1.007	0.0474	23.23
0.042	0.0500	0.065	0.062	6.21	1.128	0.0514	25.22
0.051	0.0499	0.072	0.070	6.97	1.220	0.0566	27.74
0.061	0.0500	0.077	0.075	7.50	1.356	0.0600	29.43
0.073	0.0500	0.086	0.083	8.34	1.460	0.0652	31.99
0.084	0.0500	0.093	0.091	9.06	1.545	0.0696	34.13
0.093	0.0500	0.099	0.097	9.69	1.600	0.0732	35.93
0.102	0.0500	0.105	0.102	10.21	1.666	0.0761	37.35
0.110	0.0500	0.108	0.105	10.50	1.746	0.0778	38.15
0.119	0.0500	0.115	0.112	11.25	1.764	0.0818	40.12
0.134	0.0500	0.122	0.119	11.93	1.873	0.0853	41.85

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00455	1.34	0.04	9.80	9.71	16.19	0.13
0.00564	2.10	0.09	12.74	12.56	20.94	0.14
0.00592	2.75	0.15	16.55	16.24	27.07	0.16
0.00666	3.36	0.21	18.26	17.84	29.74	0.17
0.00685	3.80	0.26	20.51	19.98	33.30	0.18
0.00782	4.60	0.35	22.07	21.38	35.64	0.19
0.00812	5.19	0.43	24.53	23.66	39.44	0.20
0.00834	5.70	0.52	26.66	25.63	42.72	0.21
0.00835	6.00	0.58	28.52	27.36	45.59	0.21
0.00860	6.42	0.66	30.03	28.72	47.87	0.22
0.00918	7.01	0.74	30.90	29.43	49.05	0.22
0.00876	7.03	0.79	33.09	31.51	52.52	0.23
0.00934	7.82	0.93	35.10	33.23	55.39	0.24

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.14	7.05	0.0651	0.0332	0.0348	78008
0.04	1.30	6.85	0.0564	0.0298	0.0316	128168
0.06	1.36	6.78	0.0616	0.0291	0.0314	190877
0.06	1.45	6.67	0.0540	0.0274	0.0298	232012
0.07	1.47	6.63	0.0554	0.0270	0.0296	275903
0.07	1.58	6.50	0.0457	0.0253	0.0278	325333
0.08	1.61	6.46	0.0457	0.0248	0.0276	380853
0.09	1.64	6.43	0.0457	0.0245	0.0274	430108
0.10	1.64	6.43	0.0478	0.0245	0.0276	468632
0.10	1.66	6.40	0.0468	0.0241	0.0273	507400
0.11	1.72	6.33	0.0418	0.0233	0.0265	543210
0.11	1.68	6.38	0.0483	0.0239	0.0273	577040
0.12	1.73	6.32	0.0442	0.0231	0.0266	639237

Table 5.33 R5 Slope=0.010

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0100	0.040	0.035	3.52	0.568	0.0315	3.09
0.022	0.0100	0.052	0.047	4.70	0.780	0.0406	3.99
0.031	0.0100	0.062	0.057	5.66	0.913	0.0476	4.67
0.040	0.0096	0.071	0.066	6.59	1.012	0.0540	5.30
0.051	0.0100	0.081	0.076	7.57	1.123	0.0604	5.93
0.063	0.0100	0.092	0.087	8.66	1.212	0.0672	6.59
0.076	0.0100	0.101	0.096	9.60	1.319	0.0727	7.13
0.088	0.0100	0.114	0.109	10.86	1.351	0.0797	7.82
0.099	0.0100	0.117	0.112	11.15	1.480	0.0813	7.97
0.112	0.0100	0.130	0.125	12.53	1.490	0.0884	8.67
0.122	0.0100	0.137	0.132	13.24	1.536	0.0919	9.01
0.132	0.0100	0.141	0.136	13.64	1.613	0.0938	9.20
0.145	0.0100	0.154	0.149	14.94	1.618	0.0997	9.78

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00324	1.00	0.04	2.07	2.00	3.34	0.06
0.00436	1.74	0.08	2.77	2.60	4.34	0.07
0.00483	2.26	0.13	3.33	3.08	5.13	0.07
0.00501	2.66	0.18	3.88	3.53	5.88	0.08
0.00531	3.15	0.24	4.46	3.98	6.63	0.08
0.00538	3.55	0.31	5.10	4.48	7.47	0.09
0.00573	4.09	0.39	5.65	4.86	8.11	0.09
0.00531	4.16	0.45	6.39	5.49	9.15	0.10
0.00622	4.96	0.55	6.56	5.46	9.09	0.10
0.00564	4.89	0.61	7.38	6.15	10.25	0.10
0.00569	5.13	0.68	7.79	6.44	10.73	0.10
0.00611	5.62	0.77	8.03	6.50	10.83	0.10
0.00566	5.54	0.83	8.79	7.14	11.90	0.11

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.04	0.97	7.27	0.0113	0.0176	0.0182	71599
0.05	1.15	7.04	0.0059	0.0152	0.0158	126801
0.06	1.23	6.94	0.0047	0.0144	0.0151	173864
0.07	1.26	6.90	0.0043	0.0138	0.0145	218645
0.08	1.30	6.84	0.0037	0.0137	0.0145	271493
0.09	1.32	6.83	0.0038	0.0136	0.0145	325918
0.10	1.36	6.77	0.0031	0.0132	0.0141	383838
0.11	1.31	6.84	0.0043	0.0137	0.0148	430739
0.11	1.41	6.70	0.0024	0.0127	0.0135	481166
0.13	1.34	6.79	0.0037	0.0133	0.0145	526687
0.13	1.35	6.79	0.0037	0.0133	0.0145	564292
0.14	1.39	6.73	0.0028	0.0128	0.0139	604950
0.15	1.34	6.80	0.0040	0.0133	0.0147	645305

Table 5.34 R5 Slope=0.015

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0150	0.036	0.031	3.12	0.641	0.0283	4.16
0.022	0.0150	0.047	0.042	4.19	0.875	0.0368	5.41
0.031	0.0150	0.056	0.051	5.09	1.015	0.0435	6.40
0.043	0.0148	0.066	0.061	6.11	1.174	0.0507	7.46
0.053	0.0150	0.075	0.070	6.99	1.264	0.0567	8.34
0.063	0.0150	0.083	0.078	7.82	1.343	0.0620	9.13
0.075	0.0150	0.090	0.085	8.46	1.478	0.0660	9.71
0.086	0.0150	0.100	0.095	9.48	1.512	0.0720	10.60
0.097	0.0150	0.106	0.101	10.06	1.607	0.0753	11.09
0.109	0.0150	0.116	0.111	11.07	1.641	0.0809	11.90
0.118	0.0150	0.121	0.116	11.60	1.695	0.0837	12.31
0.129	0.0150	0.125	0.120	11.95	1.799	0.0855	12.58
0.140	0.0150	0.132	0.127	12.72	1.834	0.0893	13.14

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00477	1.32	0.04	2.75	2.67	4.45	0.07
0.00626	2.26	0.09	3.70	3.51	5.85	0.08
0.00673	2.87	0.15	4.49	4.20	7.00	0.08
0.00734	3.65	0.22	5.39	4.94	8.24	0.09
0.00733	4.08	0.29	6.17	5.60	9.34	0.10
0.00734	4.47	0.35	6.90	6.21	10.34	0.10
0.00819	5.30	0.45	7.47	6.57	10.95	0.10
0.00763	5.39	0.51	8.37	7.35	12.25	0.11
0.00812	6.00	0.60	8.88	7.68	12.79	0.11
0.00770	6.11	0.68	9.77	8.42	14.04	0.12
0.00786	6.45	0.75	10.24	8.75	14.58	0.12
0.00860	7.21	0.86	10.55	8.83	14.71	0.12
0.00843	7.38	0.94	11.23	9.35	15.59	0.12

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.16	7.02	0.0101	0.0177	0.0183	72464
0.04	1.36	6.77	0.0057	0.0155	0.0161	128693
0.05	1.44	6.68	0.0049	0.0149	0.0156	176689
0.06	1.52	6.58	0.0040	0.0142	0.0149	238194
0.07	1.53	6.57	0.0042	0.0143	0.0151	286564
0.08	1.53	6.56	0.0043	0.0143	0.0152	333157
0.08	1.62	6.45	0.0031	0.0135	0.0144	390016
0.09	1.57	6.52	0.0041	0.0140	0.0151	435664
0.10	1.62	6.45	0.0034	0.0136	0.0146	484274
0.11	1.57	6.51	0.0043	0.0140	0.0152	530801
0.12	1.59	6.49	0.0041	0.0138	0.0150	567308
0.12	1.66	6.40	0.0029	0.0132	0.0143	615018
0.13	1.64	6.43	0.0033	0.0133	0.0145	655431

Table 5.35 R5 Slope=0.020

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0200	0.034	0.029	2.86	0.699	0.0261	5.12
0.023	0.0200	0.045	0.040	4.00	0.958	0.0353	6.92
0.033	0.0200	0.054	0.049	4.91	1.120	0.0422	8.28
0.044	0.0199	0.063	0.058	5.78	1.268	0.0485	9.51
0.053	0.0200	0.069	0.064	6.41	1.378	0.0528	10.36
0.063	0.0200	0.077	0.072	7.17	1.464	0.0579	11.35
0.075	0.0200	0.084	0.079	7.88	1.586	0.0624	12.24
0.085	0.0200	0.093	0.088	8.79	1.612	0.0680	13.34
0.097	0.0200	0.098	0.093	9.35	1.729	0.0713	13.99
0.107	0.0200	0.104	0.099	9.88	1.805	0.0743	14.58
0.117	0.0200	0.112	0.107	10.71	1.821	0.0789	15.48
0.128	0.0200	0.118	0.113	11.33	1.883	0.0822	16.14
0.140	0.0200	0.126	0.121	12.07	1.933	0.0861	16.89

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00631	1.62	0.05	3.37	3.27	5.46	0.07
0.00793	2.75	0.11	4.71	4.49	7.48	0.09
0.00854	3.54	0.17	5.78	5.43	9.05	0.10
0.00910	4.33	0.25	6.81	6.31	10.51	0.10
0.00958	4.97	0.32	7.55	6.91	11.52	0.11
0.00958	5.44	0.39	8.44	7.66	12.77	0.11
0.01017	6.22	0.49	9.28	8.30	13.83	0.12
0.00936	6.24	0.55	10.35	9.25	15.42	0.12
0.01012	7.07	0.66	11.01	9.68	16.14	0.13
0.01043	7.60	0.75	11.63	10.13	16.88	0.13
0.00979	7.58	0.81	12.61	10.98	18.31	0.14
0.00991	8.00	0.91	13.34	11.53	19.21	0.14
0.00983	8.30	1.00	14.21	12.20	20.34	0.14

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.32	6.82	0.0091	0.0178	0.0184	73037
0.04	1.53	6.56	0.0058	0.0159	0.0165	135294
0.05	1.61	6.46	0.0050	0.0153	0.0160	189058
0.06	1.68	6.37	0.0044	0.0148	0.0155	245937
0.06	1.74	6.31	0.0039	0.0144	0.0152	291129
0.07	1.75	6.30	0.0040	0.0144	0.0153	338983
0.08	1.80	6.23	0.0034	0.0140	0.0149	395987
0.09	1.74	6.31	0.0047	0.0146	0.0157	438257
0.09	1.81	6.23	0.0037	0.0141	0.0151	493011
0.10	1.83	6.19	0.0034	0.0139	0.0149	536610
0.11	1.78	6.26	0.0044	0.0143	0.0155	574797
0.11	1.79	6.25	0.0044	0.0142	0.0155	619405
0.12	1.78	6.26	0.0046	0.0143	0.0157	665557

Table 5.36 R5 Slope=0.025

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0250	0.032	0.027	2.71	0.738	0.0249	6.10
0.024	0.0250	0.043	0.038	3.82	1.047	0.0339	8.31
0.036	0.0250	0.053	0.048	4.76	1.261	0.0411	10.08
0.048	0.0250	0.062	0.057	5.71	1.402	0.0479	11.76
0.057	0.0250	0.068	0.063	6.30	1.508	0.0521	12.77
0.067	0.0250	0.075	0.070	6.97	1.602	0.0566	13.87
0.079	0.0250	0.082	0.077	7.66	1.719	0.0610	14.97
0.086	0.0250	0.087	0.082	8.20	1.748	0.0644	15.79
0.095	0.0250	0.094	0.089	8.87	1.785	0.0685	16.79
0.106	0.0250	0.099	0.094	9.38	1.883	0.0715	17.52
0.115	0.0250	0.104	0.099	9.92	1.932	0.0745	18.28
0.126	0.0250	0.110	0.105	10.47	2.006	0.0776	19.03
0.138	0.0250	0.117	0.112	11.21	2.052	0.0816	20.01

S_{smooth}	$\tau_{w,\ smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w,\ bed}$ (Pa)	u_* (m/s)
0.00751	1.83	0.05	3.99	3.89	6.48	0.08
0.01000	3.32	0.13	5.62	5.37	8.95	0.09
0.01121	4.52	0.22	7.00	6.57	10.96	0.10
0.01129	5.31	0.30	8.39	7.79	12.98	0.11
0.01170	5.97	0.38	9.27	8.52	14.20	0.12
0.01182	6.56	0.46	10.26	9.34	15.57	0.12
0.01230	7.36	0.56	11.27	10.14	16.91	0.13
0.01184	7.48	0.61	12.07	10.84	18.07	0.13
0.01138	7.64	0.68	13.05	11.70	19.49	0.14
0.01196	8.39	0.79	13.80	12.23	20.38	0.14
0.01190	8.70	0.86	14.60	12.87	21.45	0.15
0.01215	9.25	0.97	15.41	13.47	22.45	0.15
0.01189	9.52	1.07	16.50	14.36	23.93	0.15

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.43	6.68	0.0092	0.0182	0.0188	73372
0.04	1.71	6.34	0.0051	0.0158	0.0164	141928
0.05	1.84	6.18	0.0039	0.0149	0.0156	207135
0.06	1.87	6.15	0.0041	0.0149	0.0156	268870
0.06	1.92	6.09	0.0038	0.0146	0.0154	314050
0.07	1.94	6.07	0.0038	0.0145	0.0154	362456
0.08	1.98	6.02	0.0034	0.0143	0.0152	419543
0.08	1.95	6.06	0.0040	0.0145	0.0155	450262
0.09	1.91	6.10	0.0047	0.0148	0.0160	488809
0.09	1.96	6.04	0.0041	0.0145	0.0156	538344
0.10	1.96	6.05	0.0043	0.0145	0.0157	576152
0.10	1.98	6.02	0.0041	0.0143	0.0156	622683
0.11	1.96	6.05	0.0045	0.0145	0.0159	669740

Table 5.37 R5 Slope=0.030

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0300	0.032	0.027	2.68	0.808	0.0246	7.24
0.022	0.0300	0.040	0.035	3.51	1.045	0.0314	9.25
0.037	0.0300	0.051	0.046	4.61	1.338	0.0400	11.76
0.047	0.0299	0.059	0.054	5.43	1.442	0.0460	13.53
0.058	0.0300	0.066	0.061	6.14	1.574	0.0510	15.00
0.068	0.0300	0.072	0.067	6.71	1.689	0.0548	16.14
0.077	0.0300	0.079	0.074	7.40	1.734	0.0594	17.47
0.087	0.0300	0.084	0.079	7.89	1.838	0.0625	18.39
0.098	0.0300	0.090	0.085	8.54	1.913	0.0665	19.56
0.108	0.0300	0.097	0.092	9.16	1.965	0.0702	20.65
0.118	0.0300	0.101	0.096	9.57	2.055	0.0726	21.35
0.127	0.0300	0.108	0.103	10.33	2.049	0.0768	22.61
0.137	0.0300	0.115	0.110	10.98	2.080	0.0804	23.66

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.00913	2.20	0.06	4.73	4.61	7.69	0.09
0.01100	3.39	0.12	6.20	5.96	9.93	0.10
0.01310	5.13	0.24	8.14	7.67	12.78	0.11
0.01263	5.70	0.31	9.59	8.97	14.95	0.12
0.01312	6.56	0.40	10.84	10.04	16.73	0.13
0.01369	7.37	0.49	11.85	10.86	18.10	0.13
0.01299	7.56	0.56	13.07	11.95	19.91	0.14
0.01363	8.35	0.66	13.93	12.61	21.02	0.14
0.01358	8.86	0.76	15.08	13.57	22.61	0.15
0.01334	9.18	0.84	16.17	14.49	24.15	0.16
0.01396	9.93	0.95	16.90	15.00	25.00	0.16
0.01285	9.69	1.00	18.24	16.24	27.07	0.16
0.01247	9.83	1.08	19.39	17.23	28.72	0.17

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.58	6.51	0.0083	0.0181	0.0187	79559
0.04	1.78	6.26	0.0058	0.0165	0.0171	131304
0.05	1.99	6.01	0.0039	0.0151	0.0158	213811
0.05	1.98	6.02	0.0046	0.0154	0.0162	265308
0.06	2.03	5.96	0.0042	0.0151	0.0160	320974
0.07	2.08	5.90	0.0038	0.0148	0.0157	370471
0.07	2.04	5.95	0.0047	0.0152	0.0162	411765
0.08	2.09	5.89	0.0041	0.0148	0.0159	459224
0.09	2.09	5.89	0.0043	0.0149	0.0160	508563
0.09	2.07	5.91	0.0047	0.0150	0.0162	551583
0.10	2.12	5.86	0.0042	0.0147	0.0159	596411
0.10	2.04	5.95	0.0057	0.0153	0.0167	629804
0.11	2.00	5.99	0.0065	0.0155	0.0171	668619

Table 5.38 R5 Slope=0.035

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.013	0.0350	0.031	0.026	2.59	0.837	0.0238	8.19
0.025	0.0350	0.041	0.036	3.62	1.151	0.0323	11.09
0.036	0.0350	0.049	0.044	4.44	1.351	0.0387	13.28
0.047	0.0349	0.057	0.052	5.21	1.504	0.0444	15.24
0.059	0.0350	0.064	0.059	5.90	1.667	0.0493	16.93
0.070	0.0350	0.071	0.066	6.58	1.773	0.0540	18.53
0.080	0.0350	0.077	0.072	7.16	1.862	0.0578	19.85
0.089	0.0350	0.082	0.077	7.71	1.924	0.0613	21.06
0.098	0.0350	0.087	0.082	8.23	1.985	0.0646	22.17
0.109	0.0350	0.094	0.089	8.87	2.048	0.0685	23.51
0.120	0.0350	0.100	0.095	9.51	2.103	0.0722	24.79
0.128	0.0350	0.105	0.100	9.96	2.142	0.0748	25.67
0.139	0.0350	0.109	0.104	10.37	2.234	0.0771	26.46

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.01020	2.39	0.06	5.34	5.21	8.69	0.09
0.01288	4.08	0.15	7.46	7.16	11.94	0.11
0.01396	5.30	0.24	9.15	8.68	14.46	0.12
0.01440	6.27	0.33	10.73	10.08	16.80	0.13
0.01536	7.43	0.44	12.15	11.28	18.80	0.14
0.01542	8.16	0.54	13.56	12.48	20.80	0.14
0.01552	8.80	0.63	14.75	13.49	22.48	0.15
0.01530	9.21	0.71	15.88	14.46	24.11	0.16
0.01520	9.63	0.79	16.95	15.37	25.62	0.16
0.01498	10.06	0.89	18.27	16.49	27.48	0.17
0.01471	10.42	0.99	19.59	17.61	29.35	0.17
0.01456	10.68	1.06	20.52	18.39	30.65	0.18
0.01522	11.51	1.19	21.36	18.98	31.63	0.18

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.03	1.66	6.40	0.0085	0.0185	0.0191	79779
0.04	1.93	6.08	0.0054	0.0165	0.0171	148721
0.04	2.05	5.94	0.0046	0.0158	0.0165	209059
0.05	2.10	5.87	0.0045	0.0156	0.0163	266981
0.06	2.19	5.77	0.0038	0.0151	0.0159	328691
0.07	2.21	5.76	0.0039	0.0151	0.0160	382723
0.07	2.22	5.74	0.0040	0.0150	0.0160	430571
0.08	2.21	5.75	0.0043	0.0151	0.0162	472023
0.08	2.21	5.75	0.0045	0.0152	0.0163	512686
0.09	2.20	5.77	0.0049	0.0153	0.0165	560844
0.10	2.18	5.79	0.0054	0.0154	0.0168	607441
0.10	2.17	5.80	0.0057	0.0155	0.0169	640641
0.10	2.21	5.75	0.0050	0.0152	0.0166	688630

Table 5.39 R5 Slope=0.040

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0400	0.029	0.024	2.40	0.833	0.0222	8.72
0.023	0.0400	0.038	0.033	3.31	1.158	0.0298	11.70
0.033	0.0400	0.045	0.040	4.04	1.361	0.0356	13.97
0.040	0.0399	0.052	0.047	4.66	1.432	0.0403	15.82
0.050	0.0400	0.057	0.052	5.18	1.609	0.0442	17.33
0.060	0.0400	0.064	0.059	5.90	1.695	0.0493	19.35
0.073	0.0400	0.070	0.065	6.53	1.863	0.0536	21.04
0.082	0.0400	0.075	0.070	7.04	1.941	0.0570	22.37
0.093	0.0400	0.081	0.076	7.59	2.042	0.0606	23.77
0.106	0.0400	0.088	0.083	8.28	2.134	0.0649	25.46
0.117	0.0400	0.094	0.089	8.89	2.193	0.0686	26.91
0.126	0.0400	0.098	0.093	9.25	2.270	0.0707	27.74
0.142	0.0400	0.104	0.099	9.87	2.398	0.0743	29.14

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.01112	2.42	0.06	5.65	5.53	9.22	0.10
0.01451	4.24	0.14	7.79	7.51	12.52	0.11
0.01582	5.53	0.22	9.51	9.07	15.11	0.12
0.01483	5.86	0.27	10.96	10.42	17.36	0.13
0.01657	7.18	0.37	12.20	11.45	19.09	0.14
0.01589	7.69	0.45	13.89	12.98	21.64	0.15
0.01717	9.03	0.59	15.37	14.19	23.66	0.15
0.01717	9.61	0.68	16.57	15.22	25.37	0.16
0.01753	10.42	0.79	17.87	16.29	27.15	0.16
0.01746	11.11	0.92	19.49	17.65	29.42	0.17
0.01714	11.53	1.03	20.93	18.88	31.47	0.18
0.01763	12.23	1.13	21.78	19.52	32.53	0.18
0.01842	13.42	1.32	23.24	20.59	34.32	0.19

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.02	1.72	6.33	0.0087	0.0190	0.0195	74074
0.03	2.03	5.96	0.0051	0.0166	0.0172	138097
0.04	2.16	5.81	0.0043	0.0159	0.0165	193890
0.05	2.12	5.86	0.0054	0.0164	0.0172	230837
0.05	2.26	5.70	0.0041	0.0155	0.0163	284252
0.06	2.23	5.73	0.0049	0.0159	0.0168	334262
0.07	2.33	5.62	0.0040	0.0153	0.0162	399672
0.07	2.34	5.61	0.0041	0.0153	0.0163	442765
0.08	2.37	5.57	0.0039	0.0151	0.0161	494812
0.08	2.37	5.57	0.0041	0.0151	0.0163	553814
0.09	2.35	5.59	0.0046	0.0153	0.0165	601697
0.09	2.38	5.55	0.0042	0.0151	0.0163	642038
0.10	2.44	5.49	0.0038	0.0147	0.0160	712315

Table 5.40 R5 Slope=0.045

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0450	0.028	0.023	2.30	0.870	0.0214	9.43
0.023	0.0450	0.038	0.033	3.26	1.176	0.0294	12.98
0.034	0.0450	0.045	0.040	4.01	1.413	0.0354	15.61
0.043	0.0449	0.052	0.047	4.71	1.521	0.0407	17.98
0.053	0.0450	0.058	0.053	5.27	1.676	0.0448	19.79
0.064	0.0450	0.064	0.059	5.87	1.817	0.0491	21.67
0.073	0.0450	0.069	0.064	6.37	1.910	0.0525	23.20
0.082	0.0450	0.073	0.068	6.81	2.007	0.0555	24.50
0.093	0.0450	0.080	0.075	7.48	2.072	0.0599	26.43
0.105	0.0450	0.086	0.081	8.08	2.166	0.0637	28.10
0.116	0.0450	0.092	0.087	8.69	2.225	0.0674	29.75
0.127	0.0450	0.097	0.092	9.15	2.313	0.0701	30.95
0.137	0.0450	0.103	0.098	9.78	2.335	0.0738	32.56

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.01276	2.67	0.06	6.09	5.97	9.95	0.10
0.01523	4.39	0.14	8.63	8.35	13.91	0.12
0.01720	5.97	0.24	10.62	10.14	16.90	0.13
0.01651	6.59	0.31	12.48	11.86	19.77	0.14
0.01764	7.76	0.41	13.96	13.14	21.90	0.15
0.01837	8.85	0.52	15.55	14.51	24.18	0.16
0.01854	9.55	0.61	16.87	15.65	26.09	0.16
0.01902	10.36	0.71	18.04	16.63	27.71	0.17
0.01833	10.77	0.81	19.81	18.20	30.34	0.17
0.01846	11.53	0.93	21.40	19.54	32.57	0.18
0.01805	11.93	1.04	23.02	20.94	34.91	0.19
0.01851	12.73	1.16	24.24	21.91	36.51	0.19
0.01762	12.75	1.25	25.90	23.41	39.02	0.20

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.02	1.83	6.20	0.0078	0.0188	0.0193	74303
0.03	2.08	5.90	0.0058	0.0172	0.0178	138304
0.04	2.25	5.70	0.0045	0.0162	0.0168	199941
0.05	2.24	5.72	0.0053	0.0165	0.0173	247749
0.05	2.33	5.61	0.0046	0.0160	0.0168	300539
0.06	2.39	5.54	0.0042	0.0157	0.0165	356844
0.06	2.42	5.52	0.0042	0.0156	0.0165	401430
0.07	2.46	5.47	0.0040	0.0154	0.0164	445531
0.07	2.42	5.51	0.0046	0.0157	0.0168	496265
0.08	2.43	5.50	0.0047	0.0156	0.0168	551471
0.09	2.41	5.52	0.0052	0.0158	0.0171	599638
0.09	2.44	5.49	0.0050	0.0156	0.0169	648787
0.10	2.38	5.55	0.0060	0.0160	0.0175	688788

Table 5.41 R5 Slope=0.050

Discharge (m^3/s)	Slope	$y_{measured}$ (m)	y_a (m)	y_a/k	Velocity (m/s)	R_h (m)	τ_w (Pa)
0.012	0.0500	0.028	0.023	2.27	0.881	0.0211	10.35
0.022	0.0500	0.036	0.031	3.14	1.168	0.0284	13.94
0.032	0.0500	0.044	0.039	3.87	1.378	0.0343	16.81
0.043	0.0500	0.050	0.045	4.52	1.584	0.0393	19.28
0.051	0.0500	0.055	0.050	4.99	1.703	0.0428	20.99
0.062	0.0500	0.062	0.057	5.69	1.816	0.0478	23.46
0.072	0.0500	0.066	0.061	6.12	1.961	0.0508	24.93
0.082	0.0500	0.073	0.068	6.76	2.022	0.0552	27.06
0.094	0.0500	0.079	0.074	7.37	2.126	0.0592	29.02
0.106	0.0500	0.085	0.080	7.96	2.219	0.0629	30.86
0.116	0.0500	0.089	0.084	8.40	2.302	0.0656	32.19
0.126	0.0500	0.096	0.091	9.06	2.318	0.0696	34.13
0.138	0.0500	0.101	0.096	9.64	2.386	0.0730	35.79

S_{smooth}	$\tau_{w, smooth}$ (Pa)	F_{side} (N)	F_{total} (N)	F_{bed} (N)	$\tau_{w, bed}$ (Pa)	u_* (m/s)
0.01331	2.76	0.06	6.68	6.56	10.93	0.10
0.01572	4.38	0.14	9.24	8.97	14.94	0.12
0.01706	5.74	0.22	11.39	10.95	18.24	0.14
0.01879	7.24	0.33	13.31	12.66	21.09	0.15
0.01939	8.14	0.41	14.69	13.87	23.12	0.15
0.01900	8.91	0.51	16.75	15.73	26.22	0.16
0.02042	10.18	0.62	18.01	16.76	27.94	0.17
0.01946	10.53	0.71	19.89	18.47	30.78	0.18
0.01960	11.38	0.84	21.69	20.01	33.36	0.18
0.01969	12.15	0.97	23.43	21.49	35.82	0.19
0.02001	12.88	1.08	24.72	22.56	37.59	0.19
0.01877	12.81	1.16	26.66	24.34	40.57	0.20
0.01867	13.36	1.29	28.37	25.79	42.99	0.21

D_h (m)	Froude Number	A_r	Surface Roughness, k_s (m)	Eqv. Manning's n	Bed Manning's n	Reynolds Number
0.02	1.87	6.15	0.0085	0.0194	0.0199	74372
0.03	2.10	5.87	0.0065	0.0178	0.0185	132770
0.04	2.24	5.72	0.0057	0.0171	0.0178	188958
0.05	2.38	5.56	0.0046	0.0163	0.0171	249109
0.05	2.43	5.50	0.0044	0.0161	0.0169	291512
0.06	2.43	5.50	0.0049	0.0162	0.0172	347436
0.06	2.53	5.39	0.0040	0.0156	0.0166	398671
0.07	2.48	5.44	0.0048	0.0160	0.0171	446137
0.07	2.50	5.42	0.0049	0.0160	0.0171	503077
0.08	2.51	5.41	0.0050	0.0159	0.0172	558483
0.08	2.54	5.38	0.0049	0.0158	0.0171	604167
0.09	2.46	5.47	0.0062	0.0163	0.0178	645161
0.10	2.45	5.48	0.0065	0.0164	0.0179	696266