

Comparative Study of Equivalent Manning Roughness Coefficient for Channel with Composite Roughness

Djajadi, R.¹

Abstract: This paper reviews the applicability of nine selected expressions in determining the equivalent value of the Manning coefficient of roughness. For this purpose, a prismatic 4m-long and 0.05m-wide trapezoidal-shape channel was constructed, namely the homogeneous channel and the composite channel. The homogeneous channel had the same surface lining, whereas the composite channel had two different surface linings. Four different lining materials were considered: plaster, small, medium, and large-sized aggregates. The homogeneous channel showed a reliable Manning coefficient prediction, provided that a uniform flow was achieved. The roughness of the composite channel can be predicted accurately by the nine expressions; the average was 0.96, with standard deviation of 11.13%. Out of the nine expressions, the expression that considers wet-perimeter as its main parameter showed the best estimate. The error was about 2% with standard deviation of 5.15%. This can be actually traced back to the limited width of the test channel, thereby increasing the role of wet perimeter.

Keywords: manning coefficient, open channel, uniform flow, composite roughness

Introduction

Water flowing in an open channel runs in relatively complex manner due to various influencing factors, including slope steepness, surface roughness, and the so-called hydraulic radius. The Manning equation [1], which was introduced about a century ago, attempts to capture the essential features of these factors. This empirical equation offers a simple yet reliable expression and indeed has a physical meaning rooted in it. Accordingly, the average velocity at a given open-channel section v can be simply related to the abovementioned factors in the following equation:

$$v = \frac{1}{n} \times R^{2/3} \times S^{1/2} \quad (1)$$

where n is a parameter that indicates the friction provided by channel lining, the so-called *Manning coefficient of roughness*, R the hydraulic radius (in m unit), and S the channel gradient.

Despite the straightforwardness of the Manning equation, one difficulty arises in determining the Manning coefficient n .

Unlike the other two factors (R and S), which can be quantitatively measured, the n value has to be determined rather qualitatively. In principle, it depends on the characteristic of run-off surface. The rougher the surface, the larger the n value, and hence the slower the resulting average water velocity v is. For instance, a channel with concrete lining would yield an n -value of approximately 0.015, whilst one with gravel lining would correspond to about 0.020. These factors are available in many literatures [2, 3]. The selection of n value would consequently not pose a significant problem, provided that a comparable roughness of channel lining exists.

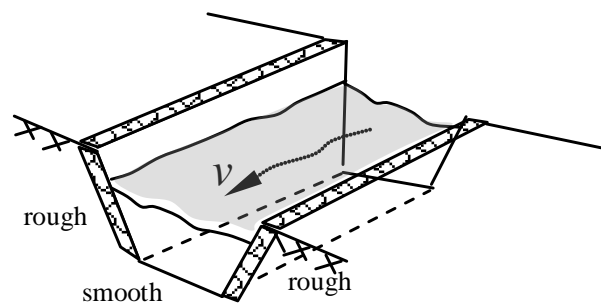


Figure 1. Illustration of a composite channel

Situation arises, however, where the roughness of channel lining in one side differ from those of the other sides. For an illustrative purpose, consider a unit length open channel as shown in Fig.1. The sidewall linings may differ to the bottom one as it-built (composite channel) or due to ill-conditioned. Generally speaking, the average roughness of the channel has changed and how it influence the water flowing is not well understood.

¹ Civil Engineering Department, Faculty of Civil Engineering and Planning, Petra Christian University. Siwalankerto 121-131, East Java, Indonesia
Email: ruslan@petra.ac.id

Note: Discussion is expected before November, 1st 2009, and will be published in the "Civil Engineering Dimension" volume 12, number 1, March 2010.

Received 7 November 2008; revised 10 February 2009; accepted 3 April 2009.

Fortunately, a number of rather diverse expressions exist to estimate the average roughness of open channel, an equivalent Manning coefficient n_e [2, 4, 5]. Nevertheless, as the expressions were derived from various fundamental assumptions, it can be said that one expression will more suit to a certain situation, and less to others.

The objective of this paper is therefore to conduct a comparative study on the applicability of several expressions in calculating n_e , as no direct comparisons have been yet undertaken. A prismatic open channel was accordingly constructed in which the surface was varied as the primary experiment variables. Two channel types were made: a homogeneous channel, which had a uniform lining material, and a composite channel, which had two combination lining materials.. The former was intended to verify the accuracy of the experiment devices, while the later was designed to study the effects of different lining surface.

Attention was given to the differences between the measured and the predicted n_e values

Literature Review

Manning Coefficient

The characteristic of channel-lining surface can be used as an indicator that control the velocity of water flow. Apart from its roughness, different material type also yields different value of n value. A typical n value is given in Table 1.

Table 1. Typical Value of Manning Coefficient of Roughness [2]

| Material Type | Manning Coefficient n |
|------------------|-------------------------|
| Soil | 0.025 |
| Concrete | 0.015 |
| Gravel | 0.020 |
| Wood | 0.013 |
| Flat steel | 0.012 |
| Corrugated steel | 0.025 |
| Glass | 0.010 |

Equivalent Manning Coefficient

Many expressions are currently available to be used to estimate the average roughness of a given open channel, which commonly known as the equivalent Manning coefficient n_e . The author would recall nine distinguished expressions, which hereafter designated as Expression 1 to 9; three are picked up from Ref. 2, two from Ref. 4, and the other four from Ref. 5. These nine expressions are listed as follows:

- Expression 1

The expression shown in Eq. 2 was originally proposed by Horton [6] and Einstein [7]. The core assumption of this expression is that, at any given section of a channel, the average velocity always equals to the corresponding total average velocity.

$$n_e = \left(\frac{(P_1 n_1^{1.5} + P_2 n_2^{1.5} + \dots + P_N n_N^{1.5})}{P} \right)^{\frac{2}{3}} \tag{2}$$

- Expression 2

This expression was intensively used by Pavlovskii [8], Muhlhofer [9], Einstein & Banks [10]. It is assumed that total resistance force equals to the sum of all resistance forces in each section. This assumption yields the following:

$$n_e = \left(\frac{(P_1 n_1^2 + P_2 n_2^2 + \dots + P_N n_N^2)}{P} \right)^{\frac{1}{2}} \tag{3}$$

- Expression 3

In 1993, Lotter [11] derived the n_e value based on the assumption of the equality of total discharge to the sum of all discharge of each section. The prediction of n_e is given by:

$$n_e = \frac{P \times R^{\frac{5}{3}}}{\left(\frac{P_1 R_1^{\frac{5}{3}}}{n_1} + \frac{P_2 R_2^{\frac{5}{3}}}{n_2} + \dots + \frac{P_N R_N^{\frac{5}{3}}}{n_N} \right)} \tag{4}$$

- Expression 4

Another simplified relationship was proposed by Cox [12] as follow:

$$n_e = \frac{(A_1 n_1 + A_2 n_2 + \dots + A_N n_N)}{A} \tag{5}$$

In the same year, he also proposed another simplified expression, designated in this paper as Expression 5. The expression is known as Colebatch Method [12] and is given as shown in Equation 6 .

- Expression 5

$$n_e = \left(\frac{(A_1 n_1^{1.5} + A_2 n_2^{1.5} + \dots + A_N n_N^{1.5})}{A} \right)^{\frac{2}{3}} \tag{6}$$

The next four expressions are taken from Soong and Hoffmann [5]

- Expression 6

This expression is commonly known as shear force II method. The value of n_e is given by in the following relationship

$$n_e = \frac{\sum (P_i R_i^{1/3} n_i)}{P R^{1/3}} \quad (7)$$

- Expression 7

This expression commonly known as shear force II method. The approximate value of n_e is given by

$$n_e = \frac{\sum (P_i R_i^6 n_i)}{P R^{1/6}} \quad (8)$$

- Expression 8

In 1960, Felkel used the following expression to obtain the value of n_e as given by:

$$n_e = \frac{P}{\sum \left(\frac{P_i}{n_i} \right)} \quad (9)$$

- Expression 9

This last expression is based on the assumption of component roughness is linearly proportional to wetted perimeter. The expression is given as

$$n_e = \frac{\sum \left(\frac{P_i}{n_i} \right)}{P} \quad (10)$$

Uniform Flow

It is important, for simplicity, to ensure a uniform flow distribution while using the Manning equation (Eq. 1). The term uniform here means that the fluid velocity has to be the same magnitude and direction at any points. To ensure the uniformity of the flow, the energy gradient, the water-surface gradient, and the channel slope have to be parallel to each other (see Fig. 2). This can be found, for instance, in an infinitely long straight channel, with a similar depth and cross-sectional area (e.g.: prismatic channel).

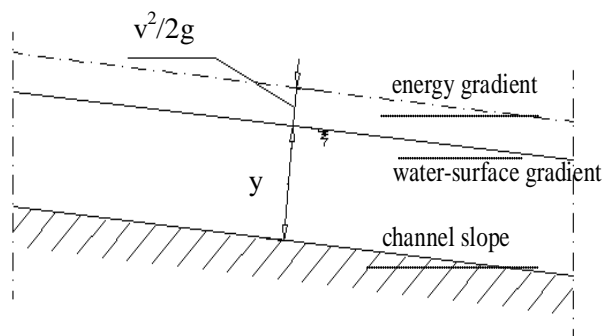


Figure 2. Illustration of uniform flow

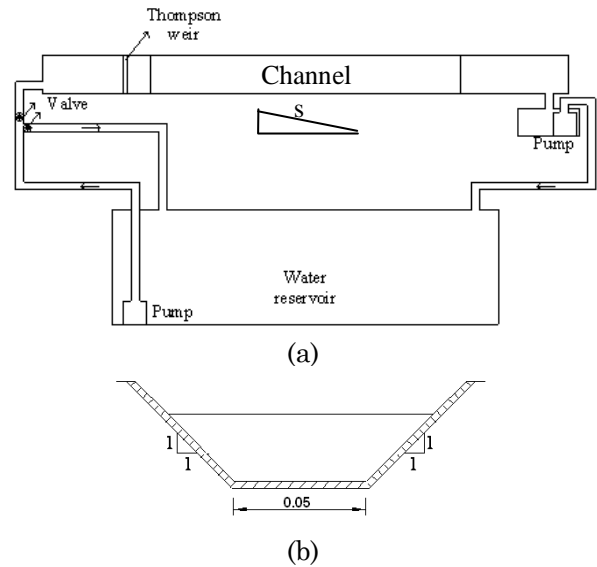


Figure 3. Schematic of the test channel: (a) General overview, (b) Typical cross section of the channel

Table 2. Experiment variables

| Case | Lining Surface Material | | Remarks |
|------|-------------------------|-----------|---------------------|
| | Bottom Surface | Sidewalls | |
| 1 | P | P | |
| 2 | SA | SA | Homogeneous Channel |
| 3 | MA | MA | |
| 4 | LA | LA | |
| 5 | P | SA | |
| 6 | P | MA | Composite Channel |
| 7 | P | LA | |
| 8 | SA | LA | |

Note:

P: Plaster; SA: Small-sized aggregate (2-3 mm); MA: Medium-sized aggregate (7-10 mm); LA: Large-sized aggregate (12-17 mm).

Experimental Program

General Overview

The experimental program involved the testing of a laboratory-scale channel with various channel lining roughness. The schematic of the channel is shown in Fig. 3.

The channel was 4 m long and 0.05 m wide with a typical cross section as shown in Fig. 3(b). The side wall of the channel was made 45° inclined ($z = 1$). The longitudinal gradient of the channel S was fixed at 0.005.

The primary variable of the test was the roughness of channel lining that was achieved through the use of different materials. Eight experimental cases were carried out in total as summarized in Table 2.

Construction of the channel

The channel was made of bricks, with various finishing materials as listed in Table 2. The plaster (P) was made of mortar with cement and sand ratio of 1:3. To obtain a smooth surface, a cement paste was applied as the finishing surface. For the case with aggregate, the channel was first plastered and the aggregate was then attached manually by hand.

Results and Discussions

Homogeneous Channel

The equivalent Manning coefficient n_e of the homogeneous channel, which was computed based on the Manning equation (Eq. 1), is shown in Fig. 4. Also shown in the figure is the reference values previously listed in Table 1.

The obtained values are in a good agreement with the reference ones, provided that a uniform flow of water was achieved. It is very evident as the finishing surface of the channel became rougher, the n value increased. The smallest n value was 0.0136, corresponding to a channel with plaster finishing, the smoothest surface finishing tested herein. This value implied that the roughness of the plaster surface was somewhat inbetween wood and concrete. The largest n value was 0.0286 and belonged to a channel with large-sized aggregate (LG). This value was even larger than those of stone and soil. The protruding aggregates from the channel surface was most likely the potential factor for this substantial increase as the aggregate size was comparatively large compared to the width of the channel.

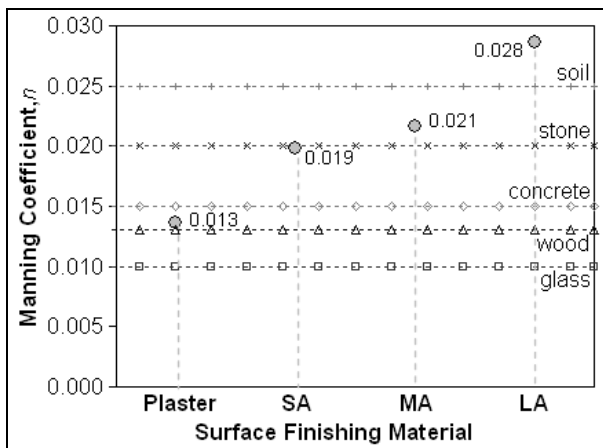


Figure 4. Comparison of the obtained and the reference n values for homogeneous channel. (Note: solid circles are the obtained values).

Composite Channel

Employing a similar procedure likewise in the homogeneous channel, the n_e value of the composite channel is listed in Table 3. The ratio of the n_e values

predicted by the nine expressions to the ones observed from the experiment is shown in Fig. 5.

Table 3. Equivalent Manning Coefficient of Composite Channel (Experiment)

| Method | Experiment Case | | | |
|------------|-----------------|--------|--------|--------|
| | P-SA | P-MA | P-LA | SA-LA |
| Experiment | 0.0166 | 0.0184 | 0.0205 | 0.0224 |
| 1 | 0.0168 | 0.0178 | 0.0220 | 0.0246 |
| 2 | 0.0169 | 0.0180 | 0.0226 | 0.0248 |
| 3 | 0.0127 | 0.0128 | 0.0132 | 0.0184 |
| 4 | 0.0152 | 0.0157 | 0.0177 | 0.0223 |
| 5 | 0.0153 | 0.0159 | 0.0183 | 0.0225 |
| 6 | 0.0157 | 0.0164 | 0.0195 | 0.0230 |
| 7 | 0.0173 | 0.0183 | 0.0225 | 0.0254 |
| 8 | 0.0160 | 0.0166 | 0.0186 | 0.0236 |
| 9 | 0.0166 | 0.0175 | 0.0213 | 0.0244 |

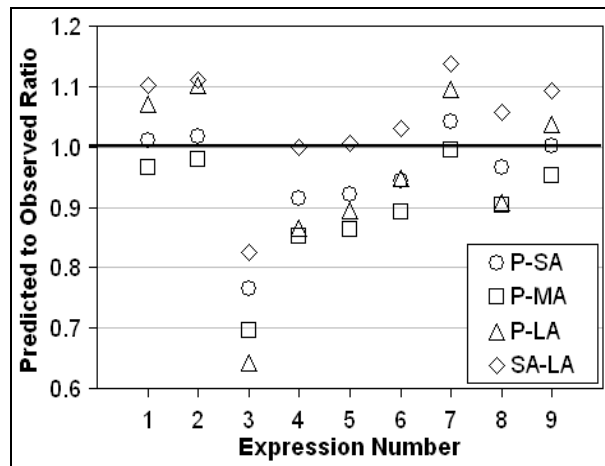


Figure 5. Predicted to Obtained n_e values of composite channel

In general, the predicted values were fair enough, although some entries were rather erratic (particularly those obtained from Expression 3). Some entries matched with the observed value at their lower bound (e.g.: Expression 1, 2, 7, and 9), and some others at their upper bound (e.g.: Expression 4, 5, 6, 8). This means the former group would be more accurate in estimating the equivalent roughness n_e of a channel with smooth bottom surface and slightly coarser sidewalls. On the other hand, the later group can serve a better estimation in the case of a waterway with slightly rough bottom surface and much rougher sidewalls.

To obtain the most reliable expression, the average of the predicted values obtained from the four experimental cases was examined and listed in Table 4. Out of the nine expressions employed, the most accurate one is the Expression 9. The error was just about 2% and average standard deviation of 5.15%. Meanwhile, the most consistent prediction is shown by Expression 6 with 4.97% deviation, but with slightly larger error (5%).

Table 4. Ratio of Predicted to Observed n_e values of Composite Channel

| Exp. | Predicted to Observed | | | | Av. of Predicted Ratio | STD DEV % |
|------|-----------------------|------|------|-------|------------------------|--------------|
| | P-SA | P-MA | P-LA | SA-LA | | |
| 1 | 1.01 | 0.97 | 1.07 | 1.10 | 1.04 | 5.30 |
| 2 | 1.02 | 0.98 | 1.10 | 1.11 | 1.05 | 5.58 |
| 3 | 0.77 | 0.70 | 0.64 | 0.83 | 0.73 | 6.93 |
| 4 | 0.92 | 0.85 | 0.86 | 1.00 | 0.91 | 5.77 |
| 5 | 0.92 | 0.86 | 0.89 | 1.01 | 0.92 | 5.35 |
| 6 | 0.94 | 0.89 | 0.95 | 1.03 | 0.95 | 4.97 |
| 7 | 1.04 | 1.00 | 1.10 | 1.14 | 1.07 | 5.41 |
| 8 | 0.97 | 0.90 | 0.91 | 1.06 | 0.96 | 6.24 |
| 9 | 1.00 | 0.95 | 1.04 | 1.09 | 1.02 | 5.15 |
| | | | | Av.: | 0.96 | 11.13 |

The accuracy of Expression 9 (Eq. 10) implies that the so-called wet perimeter was the governing factor in determining the value of n_e . Meanwhile, the other methods were less accurate as they used different parameters such as cross-sectional area, hydraulic radius, velocity, etc.

Conclusions

The Manning equation offers a simple and straightforward method in open channel flow. One of difficult parts in using this equation is in determining the so-called equivalent surface roughness coefficient n_e . Diverse procedures currently available to estimate this coefficient, but its reliability is still unrevealed. For this purpose, two types of channel was constructed: the homogeneous channel and the composite channel. Primary variables were the lining roughness that were made of plaster (P), small- (SA), medium- (MA), large-sized aggregate (LA), and the combinations of P-SA, P-MA, P-LA, and SA-LA. The following conclusion are drawn:

1. The equivalent Manning coefficient n_e of the homogeneous channel corresponds well with the values available in literatures, provided a well-designed experimental setting was achieved. This accomplishment was primarily due to the uniformity of water flow, as designed.
2. The effectiveness of nine selected procedures in determining the equivalent Manning roughness coefficient was verified. In general, all procedures could come up to a value nearly to that observed in the experiment. Only in one procedure was the estimate rather low, with 30% deviation. The overall estimated value lies at 0.96, with 11.13% deviation.
3. The so-called “component roughness is linearly proportional to wetted perimeter method” expression was the one that always gave the best estimate in which the average error was just

about 2% with average standard deviation of 5.15%.

The accuracy of the aforementioned procedure can be actually traced back to the scale of test channel presented here in which the width was limited. This was intentionally decided to have a relatively long channel, and hence ensuring the uniformity of flow. This width limitation however had increased the role of the wet perimeter of the channel. Consequently, the procedure employed wet parameter as its main parameter gave the best estimate.

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