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The Effect of Cross-Sectional Shape on the Roughness Coefficient

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Abstract. This study examines the effect of cross-sectional shape on the value of the Manning's roughness coefficient of a channel. The study was conducted using hydraulic laboratory experiment. There were 120 scenarios with 4 different types of sections (90º, 60º, 45º and 35º) and 2 types of channel roughness (coated roughness only at the bottom of the channel and roughness coated with wire mesh on the walls and on the of the channel). To get the coefficient value, it is necessary to get a uniform flow from the experiment. From the experiments results there is a correlation between the average Manning coefficient value of each section with the difference in the shape of the cross section. Then it can be concluded from the experiment that the greatest value of the roughness coefficient is at a cross section of 90° and with the roughness being coated with wire on the walls and bottom of the channel. Chart the explaining the relathionship between the average value of the Manning coefficient obtained with the shape of the cross section, so that the equation is obtained from the graph.Then from the research it can be concluded the cross-sectional shape of the channel greatly influences the roughness coefficient.

Keywords: *coefficient roughness; cross sectional shape; uniform flow; hydraulic modeling; Manning's.*

1 Introduction

The flow of water in open channel must have a free surface. The flow conditions in open channels are complicated by the fact that the position of the free surface is likely to change with respect to time and space, also by the fact that the depth of flow, the discharge, and the slope of the channel bottom and of the free surfaces are independent[1]. Calculation of the flow in the river is often used assume that the flow is uniform, although in practice flow rivers and natural channels flow is rare absolutely uniform. The general approach is a relative solution simple and satisfying for a variety technical issues[2]. For that channel has a uniform channel geometry, the determination of the value of roughness *n* is not easier when the channels are made up of different materials. The biggest difficulty in determining the value of the Manning coefficient is determining the roughness coefficient n, because there is no certain method that really cannot be calculated[3].

Many factors affect the value of *n* and one of them is the size and shape of the channel, but there is no real evidence that the size and shape of the channel are important factors affecting the value of *n*[3]. Chow[3] insisted that, however, there was no definite evidence about the size and shape of a channel as an important factor affecting the value of resistance coefficient. This statement of Chow is as a starting point of the present investigation. Coefficient of roughness and slope channels are two factors that greatly affect the speed and depth channel flow [4]. The research results [5] prove that with different cross-sections it gives different coefficients even though it has the same surface. A channel may have value different roughness in the wet section parameters, different parts of the composite channel parameters are then represented by different Manning roughness factors[6]. Many expressions are currently available to be used to estimate the average roughness of a given open channel[7]. Determination of the value of the Manning roughness coefficient can be done using measurement data of the distribution of velocity or average flow velocity, which is a method that can produce Manning values accurately [8].

Many practical formulas regarding uniform flow have been made and published but none of these formulas meet the requirements of a good formula. The most well-known and widely used formulas are the Chezy and Manning formulas. The method of estimating the value of the Manning roughness coefficient was first carried out by Chow [3]. Chow uses an approach based on the type of material and surface roughness of the channel. Determination of the value of the Manning roughness coefficient is then arranged in n tables [3]. That the condition of the canal that produces a value of n in the manning table of the literature study originating from Ven Te Chow which is often used is not necessarily the same as the existing canal conditions [9].

Basically, the influence of the cross-sectional shape is not considered in this theory, it is only seen from the bottom of the channel and how big the grain is. In this study, experiments were carried out with the Thomson channel to determine and analyze the effect of the cross-sectional factor on the roughness coefficient value. The validity in conducting this experimental test needs to be tested under rough turbulent conditions[10].

1.1 Open Channel Flow

The flow can be divided into two, namely the flow open channel and closed channel flow. Open channel is channel through which water flows with a free water table[11]. Closed channel flow is a flow which usually occurs in pipelines that has a full flow view and is absent free water surface so that the pressure that occurs is hydraulic pressure[11]. Based on the time function, the flow can be divided into two namely is steady flow and unstedy flow, based on the function of the flow space can also be divided into two namely uniform flow and non uniform flow[6].

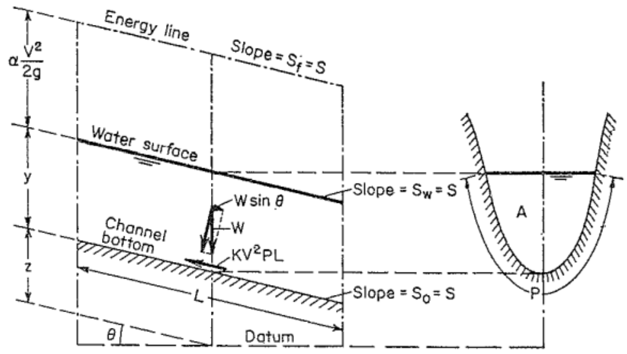

Figure 1. Uniform flow sketch *(Source: Ven The Chow).*

The uniform flow has the following main characteristics : Depth, wet area, velocity and discharge at each cross section in a straight and constant channel section and the energy line, water level and channel are parallel to each other and their slope is equal to or equal to Sf = Sw = S0 =S [3].

Open channel cross section on open channels variable flow is very irregular either to space and time, those variables are channel cross section, channel roughness, channel bottom slope, bends, and flow rate[6]. In this study, it was carried out with various cross-sectional forms, one of which was a trapezoidal shape.

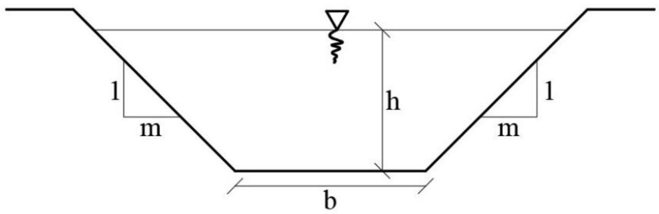

Figure 2. Trapezoidal cross section.

1.2 Manning Formula

In the century after the publication of Chézy equation in 1769, European engineers undertook extensive research into open channel flow and developed practical methods. Then Robert Manning 1889 published a simple equation that best fits the experimental results[12].

$$v = kR^{2/3}S^{1/2} \tag{1}$$

As reported by Dingman [12] that subsequent researchers replaced the constant k by its inverse 1/n. This leads to

$$v = \frac{1}{n}R^{2/3}S^{1/2} \tag{2}$$

Where: *v* (velocity), *R* (hydraulic radius), *S* (longitudinal slope), *n* (coefficient of roughness), *k* (proportionality constant representing reach conductance).

Manning's equation has been widely accepted as the resistance equation for open channel flow, replacing Chézy equations in practical application [12].

1.3 Thomson Discharge Calculations

The Thomson channel is a measuring instrument that can be shaped right triangle with angles at the bottom. An angle is a 90° angle. The amount of debit that is flowing by Thomson's measuring building this can be calculated by equation as follows [13] :

$$Q = 1{,}39h^{5/2} \tag{3}$$

where: Q(flowable discharge), h(water depth at the Thomson gate).

2 Methodology

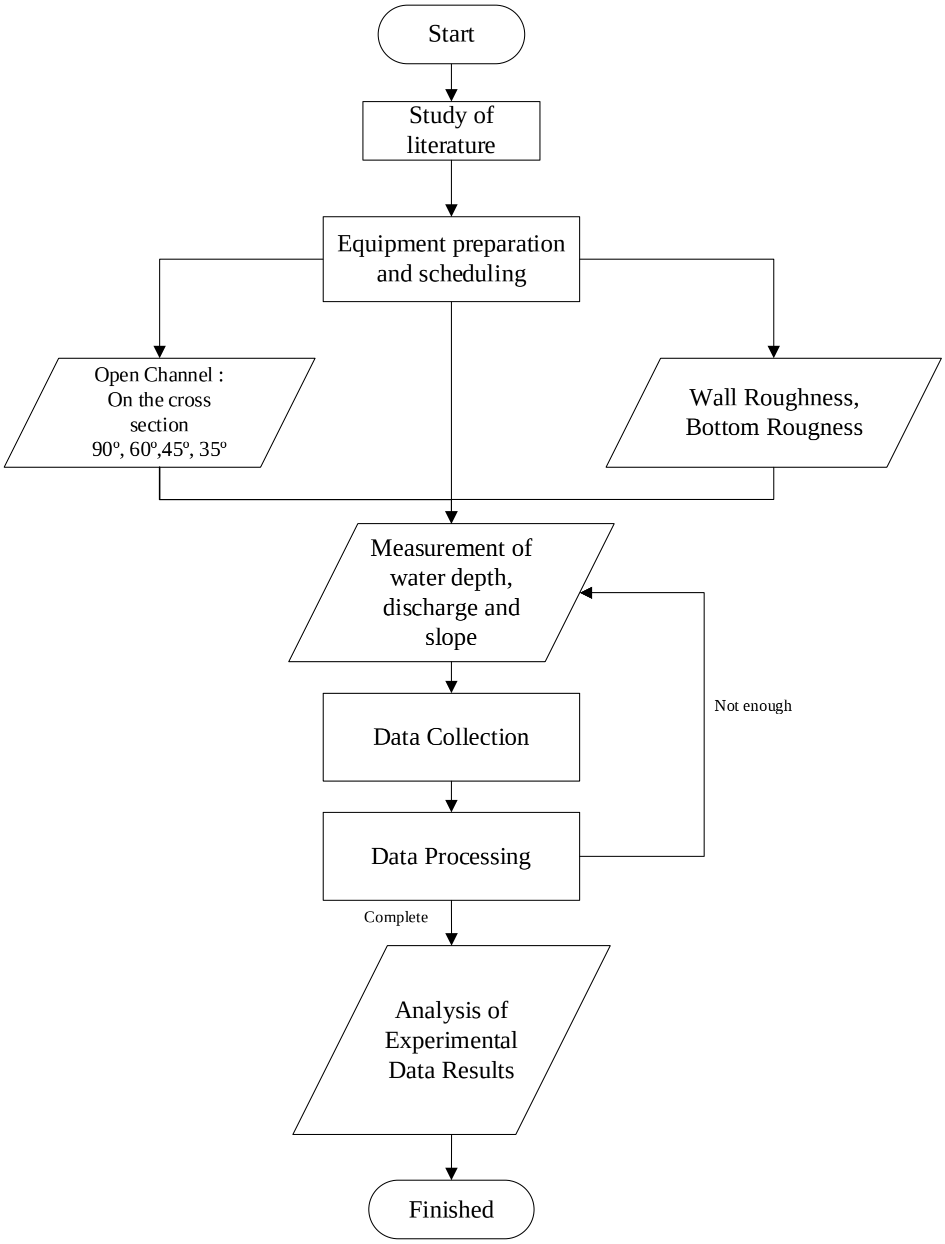

Figure 3. Flowchart

This research is hydraulic modeling that will be conducted using a thomson channel with a total length of 2.65 m and a width of 0.3 m (Figure 1) at the Hydraulics Laboratory, Bandung Institute of Technology. At the upstream of the canal there is a Thomson gauge which is useful for calculating the discharge in the flow (Figure 2).

Figure 4. Thomson Channel.

Figure 5. Thomson measuring instrument

The modeling concept creates forty scenarios, with cross-sectional shapes and roughness types. Two types of sections were evaluated: square section and trapezoidal section. There are 2 types of rudeness: the channel bottom and the channel walls are sheathed with wire and the channel bottom is wire-lined with the channel walls covered with glass.

3 Result

3.1 Experimental Modeling

Modeling starts with a uniform flow rate to get the desired value. In this study, several tools were used to carry out measurements and analyzes as follows:

1. The channel has a length of 2.65 meters and upstream there is a Thomson gauge that can calculate the flow rate. This tool is a tool used to measure hydraulic phenomena, which can flow water through a pump.
2. 4 types of sections (section 90º, 60º, 45º, 35º) with 2 types of roughness, namely wire and glass (bottom roughness and wall&bottom roughness).
3. Wire with a size of 0.5 cm x 0.5 cm.
4. Measurement of elevation difference with a waterpass.
5. Level meter for measuring flow height.
6. 100 cm ruler.
7. 1 cameras.

This research was carried out from 28 September 2022 to 23 Mei 2023 with a total of 120 scenarios for 4 types of sections and each section with 2 types of channel roughness, which are modeled as in table 1 and table 2.

Table 1. Experimental table n value with Bottom Roughness

No	Bottom Roughness (*n value*)			
	Cross Section Type			
	90º	60º	45º	35º
1	**0.02761**	0.03131	0.02700	0.02633
2	0.02709	0.02615	0.02629	0.02410
3	0.02662	0.02471	0.02399	0.02234
4	0.02518	0.02334	0.02070	0.01957
5	0.02557	0.02113	0.01815	0.01766
6	0.02401	0.01960	0.01786	0.01781
7	0.02325	0.01891	0.01616	**0.01784**
8	0.02379	0.01877	0.01595	**0.01650**
9	0.02219	0.01859	0.01560	**0.01657**
10	0.01888	0.01695	0.01552	0.01514
11	0.01807	0.01375	0.01532	0.01101
12	0.01486	0.00886	0.01447	0.00798
13	0.01277	0.00762	0.01336	0.00749
14	0.00936	0.00763	0.01207	0.00653
15	0.00919	0.00731	0.01200	0.00626
x̄	0.02056	0.01764	0.01763	0.01554

From the experiment above it can be seen the difference in the value of n value from each section.

From the table above, an n vs R graph is made to see if there are n values that are outlayer or inappropriate (maybe an error occurred during the practicum).

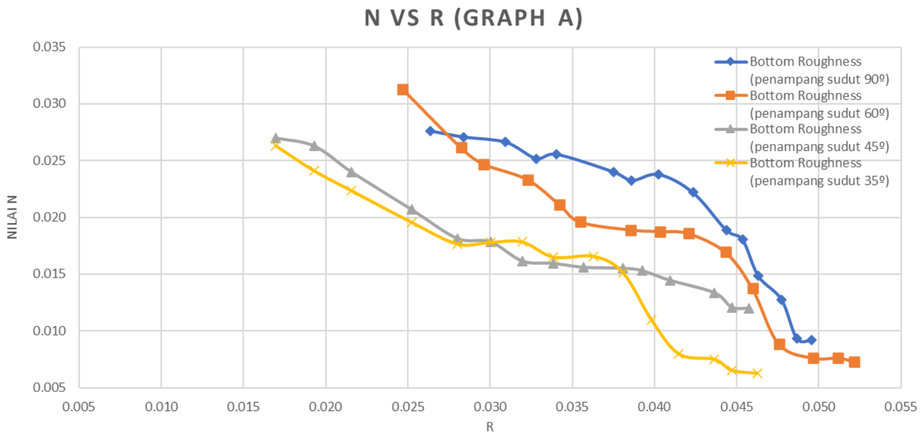

Figure 6. Graph of n vs R with Bottom Roughness (before outlayer)

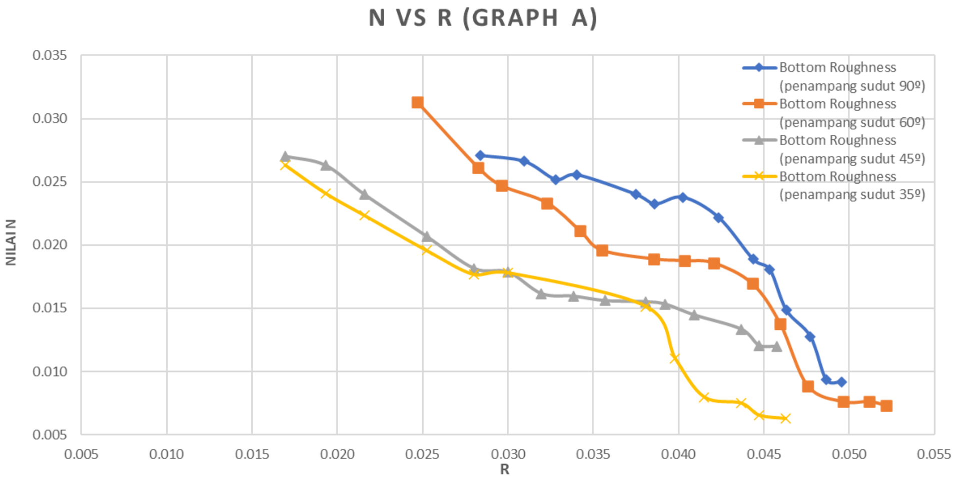

Figure 7. Graph of n vs R with Bottom Roughness (after outlayer)

Next is the n value table with wall and bottom roughness.

Table 2. Experimental table n value with Wall & Bottom Roughness

No	Wall & Bottom Roughness (*n value*)			
	Cross Section Type			
	90º	60º	45º	35º
1	0.03005	0.03563	0.03020	0.02170
2	0.03029	0.03393	0.02931	0.02188
3	0.02986	0.03397	0.02861	0.02142
4	0.02927	0.03357	0.02366	0.02033
5	0.02884	**0.02747**	0.02330	0.02041
6	0.02747	**0.02700**	0.02010	0.01951
7	0.02281	0.02679	0.01995	0.01967
8	0.02135	0.02273	0.01964	0.01807
9	0.02153	0.02291	0.01765	0.01757
10	0.02051	**0.01920**	0.01773	0.01526
11	0.02002	0.01817	0.01357	0.01545
12	0.01891	0.01535	0.01033	0.01557
13	0.01764	0.01308	0.01035	**0.01300**
14	**0.01678**	0.00861	0.00852	**0.01058**
15	0.01171	0.00734	0.00821	0.00635
x̄	0.02314	0.02305	0.01874	0.01712

From the experiment above it can be seen the difference in the value of n value from each section.

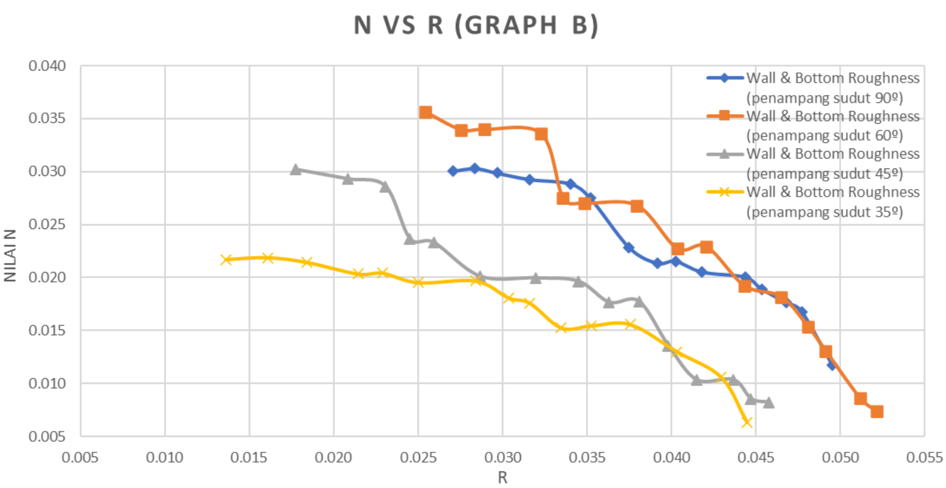

Figure 8. Graph of n vs R with Wall & Bottom Roughness (before outlayer)

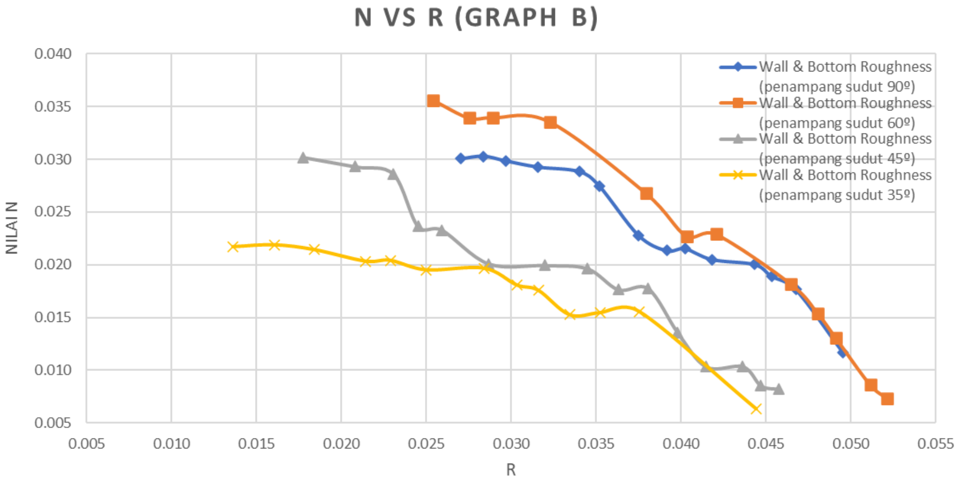

Figure 9. Graph of n vs R with Wall & Bottom Roughness (after outlayer)

From the experimental results, the results obtained were different from 4 different cross sections with 2 different types of roughness. Where the greater roughness value is at cross section 90º with the type of roughness coated with wire on the bottom and channel walls.

And next from the experimental results it was also found that the roughness value n was smaller if the channel had a smoother surface (such as glass)
From the experimental results above also obtained the shape factor value of each cross section.

Table 3. Result of shape factor value for Bottom Roughness

No	*Shape Factor Bottom Roughness*			
	Cross Section Type			
	90º	60º	45º	35º
x̄	0.020059	0.01764	0.01763	0.015185
Shape Factor		0.87951	0.87892	0.75703
%		**88%**	**88%**	**76%**

Table 4. Result of shape factor value for Wall & Bottom Roughness

No	*Shape Factor Bottom & Wall Roughness*			
	Cross Section Type			
	90º	60º	45º	35º
x̄	0.023591	0.02267	0.018743	0.017937
Shape Factor		0.96114	0.79451	0.76033
%		**96%**	**79%**	**76%**

From the results of the shape factor, it can be seen that the change in the shape of the cross section greatly affects the value of n.

After obtaining the shape factor value, the final graph can be made to obtain the equation from the regression results between the values of Manning's roughness coefficient and the side slope (m).

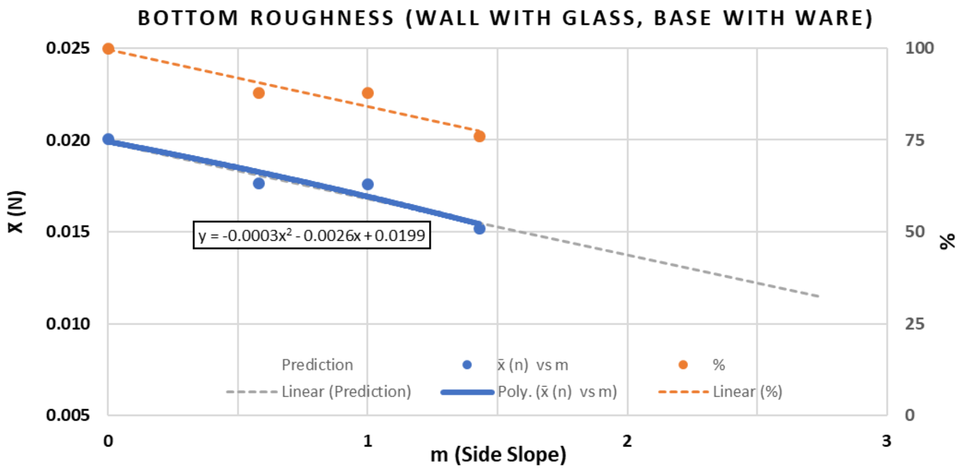

Figure 10. Graph of x̄ (n) vs m with Bottom Roughness

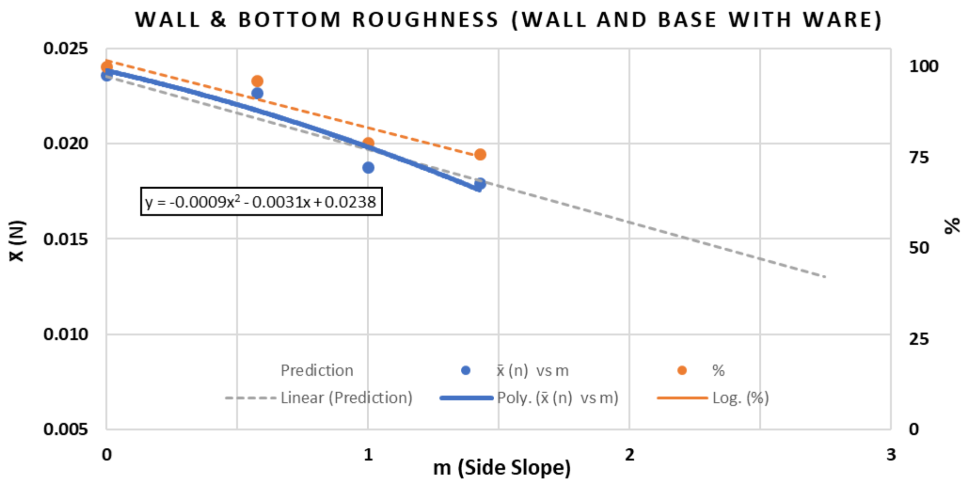

Figure 11. Graph of x̄ (n) vs m with Wall & Bottom Roughness

From the results of these equations, a new formula is obtained to determine the value of the roughness coefficient with various cross-sectional shapes.

4 Conclusion & Recommendation

4.1 Conclusion

The cross-sectional shape and channel roughness are important in the calculations and in determining the value of n. So from the experiment it was concluded:

1. Average roughness coefficient values for the Manning Formula with cross sections of 90º, 60º, 45º, 35º and with 2 types of roughness were obtained.
   The results obtained are as follows:
   - Cross section 90º (Bottom Roughness) with average 0.02005.
   - Cross section 60º (Bottom Roughness) with average 0.01764.
   - Cross section 45º (Bottom Roughness) with average 0.01763.
   - Cross section 35º (Bottom Roughness) with average 0.01585.
   - Cross section 90º (Wall & Bottom Roughness) with average 0.02359.
   - Cross section 60º (Wall & Bottom Roughness) with average 0.02267.
   - Cross section 45º (Wall & Bottom Roughness) with average 0.01874.
   - Cross section 35º (Wall & Bottom Roughness) with average 0.01793.
2. From the experimental results above it can be concluded that the 90° section with the roughness coated with wire on the bottom and channel walls has a rougher n value.
3. The influence of the type of roughness layer is very influential for the channel roughness value.
4. The most significant difference of the four forms of section is between section 90º and section 35º.
5. The cross-sectional shape effect of the channel greatly influences the roughness coefficient.
6. The equation obtained from the graph of the relationship between side slope (m) and the value of Manning's roughness coefficient.

4.2 Recommendation

Modeling is done using a channel with 4 types of cross sections and 2 types of channel roughness, it is hoped that in the future it can add to the shape of the cross section and make variations in the type of channel roughness. For discharge measurements can be used in other ways without a Thomson measuring instrument. Thankyou to the Hydraulic Modeling Laboratory for provide this research.

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