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Combining Hydraulic Roughness Measurement Results with Manning's Roughness Coefficient in Drainage Channels (A Case Study of Drainage Channels in Denpasar City, Bali Province)

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Abstract

To measure its reliability, the quality of work and materials should be assessed using objective tools and methods. For example, concrete quality is measured using tools and methods of compression testing or a hammer test tool; the results are expressed in terms of characteristic compressive strength (f'c). Steel quality is determined by the tensile test method, and the quality or strength is expressed in tensile strength (fy). The quality of the highway surface is determined by the roughness test method using the NAASRA roughness meter and the results are expressed with good, moderate and poor criteria, correlated with the International Roughness Index (IRI) value, namely good roughness if the IRI value is <75 inches/mile, moderate for IRI values between 70-170 inches/mile and poor IRI > 170 inches/mile. The hydraulic quality of the drainage channel surface to date cannot be determined with objective tools and methods. Similar to the quality of the road surface, the hydraulic quality of the channel is also determined based on the criteria: good, moderate/normal, and poor, correlated with the Manning roughness coefficient; the difference is that there is no objective value for the good, moderate, and poor criteria. The hydraulic quality of the drainage channel is one of the most important factors in determining the capacity of the channel cross-section. This study aims to determine the hydraulic quality of the channel surface objectively by combining the measurement results with the value criteria and their relationship with the Manning roughness coefficient value that has been used so far. In this case, hydraulic roughness (Hr) is measured based on the ratio of the wet surface area (Ab) to the area of its projection plane (Ap), or Hr = Ab / Ap. Samples were taken randomly on the System IV channel of Denpasar City, with a total of 30 samples. From many samples, the smallest hr value (hrmin), the largest (hrmax), and the Range (R = hrmax-hrmin) were sought. Next, a combination of the hr measurement results with the criteria (good, moderate, and poor) and their relationship with the no. The results obtained from this study are that the stone pair has good criteria if < 1.097 and no = 0.015, moderate/normal 1.097 ≤ hr ≤ 1.152 and no = 0.018, and bad if hr > 1.152 and no = 0.030.

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1 Introduction

The reliability of drainage channels in accommodating flooding is none other than their capacity. Open channel capacity is determined by flow velocity (V), which is influenced by flow resistance. Flow resistance in open channels occurs due to the frictional force between the flowing fluid and the hydraulic surface of the channel cross-section. Based on the general theory of friction, the relationship between flow resistance and hydraulic roughness is proportional: the rougher the hydraulic surface, the greater the frictional force between the fluid and the channel surface, and vice versa. Consequently, the greater the resistance to flow velocity (Li et al., 2016). The effect of hydraulic roughness on flow velocity in open channels is expressed by the hydraulic roughness coefficient. The hydraulic roughness coefficient most widely used to analyze the capacity of open channel cross-sections is the Manning roughness coefficient (n.u.).

The Manning roughness coefficient (n.u.) has been taken from several references, such as Zane, Chow, and the Department of Public Works, Directorate General of Highways, Directorate of City Road Development (for roadside channels). These references determine the Manning roughness coefficient (no) subjectively, namely, based on the type of material. For example, stone masonry material is considered to have lower hydraulic quality than concrete material, so the value of the roughness coefficient (no) of stone masonry is greater than the hydraulic roughness coefficient (no) of concrete material. In addition, the same material is also categorized based on the quality of workmanship; the better the quality of workmanship, the smaller the value (no), and vice versa. Zane (2010) relates the type of material and work quality with the Manning roughness coefficient (no) based on the minimum and maximum value categories, Chow (1959) relates the type of material and work quality with the Manning coefficient (no) based on the minimum, normal and maximum value categories, and the Department of Public Works, Directorate General of Highways, Directorate of City Road Development (1990) relates the type of material and work quality with the Manning coefficient (no) based on the value categories of excellent, good, moderate, and poor.

There is no objective standard that can be used to select one of the qualities of work or material from the existing categories, so the determination of the Manning roughness coefficient value (no) from the reference is very subjective. The quality of work/material with the categories of minimum, maximum, excellent, good/moderate, and poor does not have objective limits. However, determining and/or testing the quality of a job is one of the most important things in construction work (Sutapa et al., 2022). Almost all the quality/quality of construction work materials can be determined objectively, for example, concrete quality is determined by the characteristic compressive strength value (f'c), steel quality is determined by the tensile strength number (fy), the quality of highway surfaces is determined by the International Road Index (IRI) or Road Condition Index (RCI), but the hydraulic quality of drainage channel surfaces is still determined subjectively, namely based on the values: excellent, good, moderate/normal and poor, related to the Manning roughness coefficient number of the channel material (no).

Suparta (2018) quantified the hydraulic roughness (hr) of masonry with broadcasts based on the ratio between the wet surface area (AB) and its projected area (AP), or hr = AB/AP. The wet surface area (AB) is the surface area calculated based on the length of the wet path, measured using a wet thread (attached to the entire surface area). Meanwhile, the projected area (AP) is calculated based on the area of the flat plane. The hr value can be combined with the subjective quality contained in the references used to determine the Manning roughness coefficient (no) such as: very good, good, medium/normal, poor, minimum and maximum categories, related to the Manning roughness coefficient (no), so that it becomes a standard measure of material quality and objective (measurable) work quality.

This study aims to create a combination of subjective quality values of materials/works in the references (Zane, 2010; Chow, 1959; SNI 2830, 2008; DPU RI, 1990) and relate them to the Manning roughness coefficient (no) in each of these references. The results of this study are in the form of a combination of hydraulic roughness (hr) with subjective values of subjective hydraulic quality (very good, good, moderate/normal, poor, minimum and maximum) and their relationship with the Manning roughness coefficient (no). So that a method is obtained to determine and measure/test the quality of materials and open channel construction work that is easy, simple, and measurable.

Literature review

To measure road surface quality, AASHTO recommends the NAASRA method (SNI 03-3426-1994), with the roughness measure being the International Roughness Index (IRI). The IRI is a roughness parameter calculated based on the cumulative number of ups and downs of the road surface along the longitudinal profile divided by the distance/length of the measured surface (Sugiharto, 2004). Besides the IRI, road surface quality can also be determined based on the Road Condition Index (RCI) value, obtained using a roughometer or manually using a simple tool (tape measure) combined with visual observation. The roughometer yields the International Roughness Index (IRI) value, which is then converted to obtain the RCI value (Anisarida, 2017).

Purbosari (2012), measures the configuration of surface irregularities of an object/material using a reference profile. The reference profile used is the center profile or base profile. The center profile is a profile that is shifted to the middle between the highest and lowest points of the profile. The roughness measure is the surface area above the reference divided by the area of the reference plane. The base profile is a reference profile that is shifted down so that it touches the lowest point of the measured profile. The roughness measure is the surface area above the reference divided by the area of the reference plane. This method is widely used to measure the quality of steel cutting work results (Attari et al., 2021).

A method similar to the IRI/RCI method was carried out by Idiot (2012), who measured the surface roughness of a material/object based on the number of up and down movements, or based on the height of the incline (peak) and decline (valley). Idiot described the surface roughness of an object into 3 (three), namely: (1) statistical description, using the average value of the surface height, (2) extreme value description, namely based on the condition of the maximum peak value towards the maximum valley value or the difference between the maximum peak value and the maximum valley value, (3) texture description, namely based on the measurement results against the measurement length (traversing length). This method is often used to measure the quality of steel surface work. (Suparta, 2018) modified the Balinese style work volume measurement method by using a wet thread path attached to the work surface that is measured in the length and width directions, and then calculating the area to obtain the wet area. Suparta compared the wet area with its projected area (flat surface area) to obtain the ratio of the wet area to its projected area as follows:

$$\mathrm{hr} = \frac{AB}{AP} \quad (1)$$

Which:
hr = hydraulic roughness
AB = wet cross-sectional area
AP = projection area

$$\mathrm{AB} = \mathrm{lv \times lh \ or\ AB = ll \times lt} \quad (2)$$

Which:
lv = length of the wet track in the vertical direction.
lh = length of the wet track in the horizontal direction.
ll = length of the wet track in the longitudinal direction.
lt = length of the wet track in the transverse direction.

The wetted surface area (AB) on the wall is calculated based on the product of the horizontal wetted path length (lh) and the vertical wetted path length (lv), and the wetted surface area at the bottom of the channel is calculated based on the product of the longitudinal wetted path length (ll) and the transverse wetted path length (lt). The path lengths (lv, lh, ll, and lt) of the material surface are measured using a wet thread attached to the surface. Meanwhile, the projected area is calculated based on the flat surface area, namely, for the channel wall, it is the result of multiplying the vertical flat length by the horizontal, and for the channel base, it is the result of multiplying the transverse flat length by the longitudinal. The flow velocity formula (V) for uniform flow in an open channel according to Manning is: (Anon, 2015):

$$V = \frac{1}{n_o} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (3)$$

With the following information:
V : flow velocity.
no : Manning's roughness coefficient (depending on material and workmanship).
R : hydraulic radius.

S : channel bed slope.

Keulegan (1938), states that the Manning roughness coefficient (n) is very suitable for calculating the channel roughness coefficient in channels with large surface roughness (however, there is no explanation of how to determine the value of the surface roughness in question). Manning's formula is very simple and easy to apply, but according to Graf (1998), the Manning formula is only suitable for rough turbulent flow and at high Reynolds numbers. To be able to use the Manning formula for uniform flow, the slope of the energy line is modified to reflect energy loss due to friction (Coon, 1995). According to formula (3), the main parameter that determines the flow velocity is:

1) Nilai koefisien kekasaran Manning (n_o).
2) Kemiringan egergi (S).
3) Jari-jari girasi (R).

If the S and R parameters are kept the same, then the only factor influencing the flow velocity (V) according to formula (3) is the Manning roughness coefficient (no). The Manning roughness coefficient (no) value for masonry with a broadcast is available in several references, namely:

1) Zane (2010) determines the no value based on two categories: maximum and minimum values, as presented in Table 1.

Table 1
Manning Roughness Coefficient (no) according to Zane

Manning's Roughness Coefficient, *n*.	Manning's *n*	
Type of Pipe	Min.	Max.
Glass, brass, or copper	0.009	0.013
Smooth cement surface	0.010	0.013
Wood-stave	0.010	0.013
Vitrified sewer pipe	0.010	0.017
Cast-Iron	0.011	0.015
Concrete, precast	0.011	0.015
Cement mortar surfaces	0.011	0.015
Common-clay drainage tile	0.011	0.017
Wrought Iron	0.012	0.017
Brick with cement mortar	0.012	0.017
Riveted-steel	0.017	0.020
Cement rubble surfaces	0.017	0.030
Corrugated metal storm drain	0.020	0.024

(Source: Zane, 2010)

2) (Chow, 1959; SNI 2830, 2008) recommends n values based on 3 (three) categories, namely: minimum, normal, and maximum values, as presented in Table 2.

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Table 2
Manning's Roughness Coefficient (no) according to Chow (1959)

Type of channel and description	Minimum	Normal	Maximum
1. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
2. Unfinished, steel form	0.012	0.013	0.014
3. Unfinished, smooth wood form	0.012	0.014	0.016
4. Unfinished, rough, wood form	0.015	0.017	0.020
a. Wood			
1) Stave	0.010	0.012	0.014
2) Laminated, trested	0.015	0.017	0.020
b. Clay			
1) Common drainage tile	0.011	0.013	0.017
2) Vitrified sewer	0.011	0.014	0.017
3) Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
4) Vitrified subdrain with open joint	0.014	0.016	0.018
c. Brickwork			
1) Glazed	0.011	0.013	0.015
2) Line with cement mortar	0.012	0.015	0.017
d. Sanitary sewer casted with sewage slims, with bends and connections	0.012	0.013	0.016
e. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
f. Rubble masonry, cemented	0.018	0.025	0.030

(Source: Chow, 1959)

3. (Indonesian Department of Public Works, 1990), recommends determining the no value based on 4 (four) categories, namely: excellent, good, fair, and poor quality, as presented in Table 3.

Table 3
Manning's Roughness Coefficient (n) according to the Indonesian Department of Public Works

No	Channel Type	Very good	Good	Average	Poor
	Artificial channels, concrete, or river stone				
16.	Stone masonry channels, unfinished	0.025	0.030	0.033	0.035
17.	Like no. 16 but with finishing	0.017	0.020	0.025	0.030
18.	Concrete channels	0.014	0.016	0.019	0.021
19.	Smooth and level concrete channels	0.010	0.011	0.012	0.013
20.	Precast concrete channels with steel forms	0.013	0.014	0.014	0.015
21.	Precast concrete channels with wooden forms	0.015	0.016	0.016	0.018

(Source: Indonesian Department of Public Works, 1990)

Theoretical Basis

If the hydraulic roughness (hr) of the channel material is quantified using the comparison method between the wetted surface area (AB) and its projected area (AP) as in formula (1), then a correlation can be made between the hr value and the subjective hydraulic quality values: very good, good, moderate/normal, minimum, maximum, and poor, as well as their relationship with the Manning roughness coefficient (no) according to the reference used. The results of this correlation produce a relationship between the subjective hydraulic quality value with hr and the Manning roughness coefficient (no) according to the referenced reference. Thus, the determination of the Manning roughness coefficient (no) value can be done objectively (de FSM Russo & Camanho, 2015).

2 Materials and Methods

This research was conducted on a stone masonry drainage channel finished with a siding, in the System IV drainage channel in Denpasar City. Sampling was carried out randomly on primary, secondary, and tertiary channels. Samples were taken from accessible channels and measured well/accurately. The number of samples taken was 30 in 10 areas. Samples were taken only on the channel walls because some of the channel bottom was submerged by water flow, and some were sedimented, so that measurements could not be carried out properly/accurately. Measurements were carried out using a square measuring plot method with a length and width of 50 cm. The dimensions of the measuring plot were made with a size of 50 cm x 50 cm to anticipate the depth of the tertiary channel, which is generally relatively shallow, at the study location, around 60-70 cm. The samples taken were the length of the wet path in the vertical and horizontal directions. Each sample was measured three (3) times in the vertical direction (lv1, lv2, lv3) and horizontal direction (lh1, lh2, lh3), then averaged and used as a representative of the vertical direction (lv) and horizontal direction (lh) samples, as shown in Figure 3.

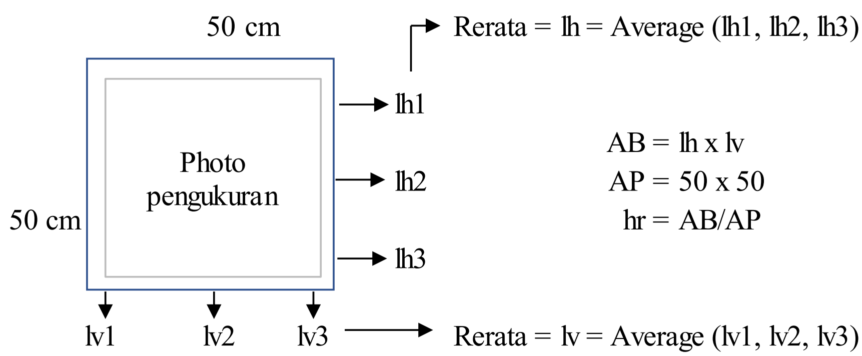

Figure 3. Sample Measurement Method and AB Calculation
(Source: skema metode pengambilan sample, 2022)

From all the data from the lv and lh measurements, the wetted surface area (AB) is calculated using formula (2) and hr using formula (1). Next, the range (R) of the hr value is found, which is the difference between the largest hr value and the smallest hr value (R = hrmax – hrmin). The hydraulic roughness values (hr) from the calculations above are grouped into several groups according to the references used so that they can be combined with the hydraulic quality as follows:

1. (Zane, 2010) groups subjective hydraulic quality values into two groups: minimum and maximum. Therefore, hydraulic roughness (hr) is also divided into two groups by creating a range of hr values from minimum hr + 1/2R and maximum hr - 1/2R. The correlation and its relationship with the Manning roughness coefficient (no.) are presented in Table 4.

Table 4
Correlation Scheme of Subjective Hydraulic Values with Hydraulic Roughness Numbers and Their Relationship with the Manning Roughness Coefficient (Zane, 2010).

No	Katagori	Hydraulic roughness (hr)	n_o
1	Min	hrmin s/d < hrmin+1/2R	0.017
2	Max	hrmin+1/2R ≥ s/d hrmax	0.030

(Source: skema analisis; Zane, 2010)

2. (Zane, 2010) groups subjective hydraulic quality values into two groups: minimum and maximum. Therefore, hydraulic roughness (hr) is also divided into two groups by creating a range of hr values from minimum hr + 1/2R and maximum hr - 1/2R. The correlation and its relationship with the Manning roughness coefficient (no.) are presented in Table 4.

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Table 4
Correlation Scheme of Subjective Hydraulic Values with Hydraulic Roughness Numbers and Their Relationship with the Manning Roughness Coefficient (Zane, 2010)

No	Katagori	Hydraulic roughness (hr)	n_o
1	Min	hrmin s/d < hrmin+1/3R	0.015
2	Normal	hrmin+1/3R ≥ s/d hrmin + 2/3R	0.018
3	Max	hrmin + 2/3R > s/d hrmax	0.030

(Source: skema analisis; Chow, 1959)

3. (DPU RI, 1990) groups the subjective values of hydraulic quality into four (4) groups, namely: very good, good, normal, and poor. Therefore, hydraulic roughness (hr) and hr are made into four (4) groups by creating a range of hr values from hrmin to hrmin + 1/4R, hrmin + 1/4R ≥ to < hrmin + 1/2R, hrmin + 3/4R ≥ to < hrmin + 3/4R ≥ hrmax, and the relationship between the Manning roughness coefficient (no.), as presented in Table 6.

Table 6
Scheme for Matching Subjective Hydraulic Values with Hydraulic Roughness Numbers and Their Relationship with the Manning Roughness Coefficient Based on the DPU RI Reference (1990)

No	Katagori	Hydraulic roughness (hr)	n_o
1	Baik sekali	hrmin s/d < hrmin + 1/4R	0.017
2	Baik	hrmin + 1/4R ≥ s/d hrmin + 2/4R	0.020
3	Sedang	hrmin + 2/4R > s/d hrmin + 3/4R	0.025
4	Jelek	hrmin + 3/4R > s/d hrmax	0.030

(Source: skema analisis; DPU RI, 1990)

3 Results and Discussions

The results of horizontal and vertical wet path measurements, as well as hydraulic roughness (hr) values at the study location, show very diverse values, as presented in Table 7.

Table 7
Data on Measurement Results of lv, lh, AB, and hr Calculations in the Denpasar City Drainage System IV Channel

No	lv	lh	AB	AP	hr
1	51.73	51.40	2,659	2,500	1.06364
2	55.70	57.33	3,193	2,500	1.2774
3	52.30	52.83	2,763	2,500	1.1053
4	52.70	53.83	2,837	2,500	1.1348
5	53.00	54.67	2,897	2,500	1.1589
6	52.63	53.00	2,790	2,500	1.1158
7	52.20	51.50	2,688	2,500	1.0753
8	53.20	52.83	2,811	2,500	1.1243
9	53.57	52.07	2,789	2,500	1.1156
10	54.03	52.03	2,812	2,500	1.1246
11	52.80	52.90	2,793	2,500	1.1172
12	53.70	53.60	2,878	2,500	1.1513
13	53.53	52.67	2,819	2,500	1.1278
14	54.47	53.47	2,912	2,500	1.1649
15	53.83	52.83	2,844	2,500	1.1377
16	52.50	52.63	2,763	2,500	1.1053
17	52.40	50.53	2,648	2,500	1.0592
18	53.23	52.67	2,804	2,500	1.1214
19	52.93	52.47	2,777	2,500	1.1109
20	51.97	51.83	2,694	2,500	1.0774
21	54.87	53.53	2,937	2,500	1.1749
22	51.57	52.10	2,687	2,500	1.0746
23	51.80	51.20	2,652	2,500	1.0609
24	51.53	50.57	2,606	2,500	1.0423
25	52.47	52.80	2,770	2,500	1.1081
26	52.00	51.73	2,690	2,500	1.0761
27	51.53	50.57	2,606	2,500	1.0423
28	53.03	52.53	2,786	2,500	1.1144
29	51.97	53.10	2,759	2,500	1.1038
30	53.33	52.40	2,795	2,500	1.1179

From Table 7, it can be seen that the HR value of the rock pairs with broadcasts in the study area varies greatly. The minimum hydraulic roughness value (hrmin = 1.04235), maximum (hrmax = 1.27739), Range (R = HRmax – HRmin = 0.16458), Average = 1.11280. The combination of subjective values of hydraulic quality with hydraulic roughness numbers (hr) and their relationship with the Manning roughness coefficient (no), for each reference, is as follows:

1. Zane (2010)
   Because Zane (2010) created two value categories: minimum and maximum, the corresponding matching groups must also be divided into two groups: (1) hrmin to less than hrmin + ½ hr, (2) ≥ hrmin + ½ hr to hrmak, as presented in Table 8.

Table 8
Results of Matching Subjective Hydraulic Quality Values with Hydraulic Roughness (hr) and Manning Roughness Coefficient (no), Using Zane (2010) References

No	Katagori	Hydraulic roughness (hr)	n_o
1	Min	1.04235 sampai < 1.12464	0.017
2	Max	1.12464 ≥ sampai 1.27739	0.030

Source: Analysis Results and Zane (2010).

2. Chow (1959)
Based on Chow's (1959) reference, the subjective hydraulic quality of channel materials is divided into minimum, normal, and maximum values. Therefore, their correlation with hr and (no) can be created, as shown in Table 9.

Table 9
Results of Correlating Subjective Hydraulic Quality Values with Hydraulic Roughness (hr) and Manning's Roughness Coefficient (no), Using Chow's (1959) Reference

No	Katagori	Hydraulic roughness (hr)	n_o
1	Min	1.04235 sampai < 1.09721	0.015
2	Normal	1.09721 ≥ sampai 1.15207	0.018
3	Max	1.15207 > sampai 1.27739	0.030

Source: Analysis Results and Chow (1959)

3. Indonesian Department of Public Works (1990).
According to Road Surface Drainage Design Instructions No. 008/T/BNKT/1990, the n value for masonry with broadcasts is determined based on four categories: Very Good (n = 0.017), Good (n = 0.020), Fair (n = 0.025), and Poor (n = 0.030). Results of Comparing Subjective Hydraulic Quality Values with Hydraulic Roughness (hr) and Manning's Roughness Coefficient (n), Using the DPU RI Reference (1990).

Table 10
Results of Comparing Subjective Hydraulic Quality Values with Hydraulic Roughness (hr) and the Relationship between Manning's Roughness Coefficient (n), Using the DPU RI Reference (1990)

No	Katagori	Hydraulic roughness (hr)	n_o
1	Baik sekali	1.04235 sampai < 1.08349	0.017
2	Baik	1.08349 ≥ sampai 1.12464	0.020
3	Sedang	1.12464 > sampai 1.16578	0.025
4	Jelek	1.20693 > sampai 1.27739	0.030

Source: Analysis Results and DPU RI (1990)

4 Conclusion

From the discussion, it can be concluded that:

a) The calculation of the wet cross-sectional area (AB) of masonry with broadcasts can be performed by measuring the wet path using a wet thread path.
b) The combination of subjective values of hydraulic quality with hydraulic roughness (hr) and its relationship with the Manning roughness coefficient (no) can be used to determine the Manning roughness coefficient (no) of the channel material, with objective, rational, and measurable results.

Conflict of interest statement
The author declared that he has no competing interests.

Statement of authorship
The author has a responsibility for the conception and design of the study. The author has approved the final article.

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