Uludağ University Journal of The Faculty of Engineering, Vol. 28, No. 2, 2023 RESEARCH

DOI: 10.17482/uumfd.1183508

A LABORATORY SCALE INVESTIGATION OF MANNING ROUGHNESS COEFFICIENT IN OPEN CHANNEL BED WITH DIFFERENT GRAIN SIZE AND SLOPES

Damla YILMAZ *
Egemen ARAS *
Babak VAHEDDOOST *

Received: 03.10.2022; revised: 02.11.2022; accepted: 11.07.2023

Abstract: Efforts for getting the maximum efficiency from the existing water resources and to implement new projects are getting more attention these days. Determining the flow resistance for the project design and control process in open channels requires sophisticated applications. It is usually essential to be aware of the characteristics of the channel and flow to determine the hydraulic roughness, which represents the resistance of the flow. Hence, empirical calculation and evaluation of the hydraulic roughness will support future design and planning processes. In this study, four different particle sizes (d_{50}= 28mm, 17.5mm, 4mm, and 1.75mm) that were fixed on blocks were used. These particle sizes were then used as the bed covering together with, three different horizontal bed slopes, and flow rates in the experiments to determine the associated Manning roughness, *n*. During the experiment, Froude number values were examined and it was determined that, in 32 experiments the flow regime can be considered as subcritical. Alternatively, the Lotter method was used to confirm the roughness values obtained by the Manning equation. It was concluded that the roughness values obtained by the selected methods have good concordance with each other.

Anahtar Kelimeler: Roughness coefficient, Open channel flows, Manning, Grain diameter

Farklı Taban Dane Çapı ve Eğimlere Sahip Açık Kanallarda Manning Pürüzlülük Katsayısının İncelenmesi

Öz: Mevcut bulunan su kaynaklarından maksimum verimi alabilmek ve yeni projeleri hayata geçirmek amacıyla yapılan çalışmalar gün geçtikçe artmaktadır. Açık kanallarda proje tasarım ve kontrol etme sürecinde akış direncini belirlemek oldukça karmaşık bir süreci gerektirir. Akışa karşı direnci temsil eden hidrolik pürüzlülüğü hesaplayabilmek için kanal ve akışın karakteristiklerini bilmek şarttır. Hidrolik pürüzlülüğün ampirik olarak hesaplanması ve değerlendirilmesi ilerde yapılacak tasarım ve planlama süreçlerine destek olacaktır. Bu çalışmada aynı boyutta bloklara yerleştirilen dört farklı dane çapına sahip agrega kullanılmıştır (d_{50}= 28mm, 17.5mm, 4mm ve 1.75mm) Deneylerde *n*, pürüzlülük katsayısının farklı zemin numuneleri kullanılarak üç farklı eğim ve debide oluşan farklılıklar gözlenmiştir. Deney süresince Froude sayısı değerleri incelenmiş ve 32 adet deneyin nehir rejiminde devam ettiği görülmüştür. Alternatif olarak, Manning denklemi ile elde edilen pürüzlülük değerlerini doğrulamak adına Lotter yöntemi kullanılmıştır ve seçilen yöntemlerle elde edilen pürüzlülük değerlerinin birbiri ile iyi uyum gösterdiği sonucuna varılmıştır.

Keywords: Pürüzlülük katsayısı, Açık kanal akımları, Manning, Dane çapı

* Deparment of Civil Engineering, Bursa Technical University, 16320 Bursa, Turkey
Correspondence Author : Damla YILMAZ (damla.yilmaz@btu.edu.tr)

1. INTRODUCTION

Conducted studies by far have tried to enhance the efficiency and the applicability of water resources. Hence, sustainability of the water resources is an important issue in terms of water consumption for long period. Likewise, studies regarding the behavior of water in open channel and the associated accuracy in the measurement of the flow has an invaluable importance for water resources planning and flood studies (Yerdelen et al., 2015).

The most important factor for the efficient use of water resources is the hydraulic and hydrological evaluation of the flow. In this context, it is necessary to examine the dynamic conditions of the open channel flows. The Manning equation, which is defined as the most suitable formula for examining the flow in the open channels, has many design applications (Merry, 2017).

The *n*, roughness coefficient in this equation changes depending on the channel conditions. The degree of roughness in open channel flow varies depending on the surface roughness of the bed material, channel cross-section and size, type and density of flow obstruction, sediment accumulation and other factors. However, the primary factors in which the roughness coefficient depends are channel slope and bed surface roughness (Gautam, 2021; Jarrett, 1985).

In many studies, the effects of changing bed material, particle diameter and size, different flow rates and slope values on the roughness coefficient were investigated (Merry, 2017; Lau and Afshar, 2013). Merry (2017) study carried out experiments on steel, sand and wavy bed in the open channel with slope ranging between 1:200 to 1:500. In this experiment different flow rates were used, and it was determined that the flow rate and the roughness coefficient had a negative correlation. It was also observed that the Manning coefficient increased as the roughness of the bed material increased. Lau and Afshar (2013) similarly studied the effect of bed material with 2mm and 5mm particle size on the roughness coefficient at different flow rates and slopes. It was determined that the bed material roughness, channel slope, and material particle size greatly affect the Manning roughness coefficient. In the experiment, it was observed that the smooth surface has a smaller Manning roughness coefficient. Ibrahim and Abdel-Mageed (2014) confirmed a comparative study between experimental and numerical models to investigate the effect of flow properties on the roughness coefficient. 72 data sets were obtained experimentally and verified numerically. In the study, six different bed materials (gravel, cement, clay, grass, formica and vegetation) and four flow rates and three outlet water levels were tested together with different bed material. The models proved that for a given bed material, the roughness coefficient is inversely proportional to the flow rate and directly proportional to the outlet water level. In the study, it has also determined that the Manning roughness coefficient is directly proportional to the hydraulic radius for a given flow rate.

In recent years, many similar studies have been carried out to determine the roughness coefficient (Ahmad et al., 2017; Abd Wahid, 2015; Wu Fu- Sheng, 2008, Doncker et al., 2009; Abood et al., 2006; Djajadi, 2009). Many factors that cause the channels to have different properties create difficulties in determining this coefficient. Especially, calculation of the coefficient in field studies is very limited and difficult. In order to determine the extent to which the parameters affect the coefficient, a laboratory study that can give fast results is required. With a laboratory scale model designed in this study, the effect of the coefficient on the flow can be examined in detail and contributes to field studies. In this study, to contribute to the existing studies, the differences caused by the *n*, roughness coefficient obtained from various soil types of four different grain diameters in three different channel slopes and flow rates are examined in the laboratory. Alternatively, the relationship between obtained variables is examined through different graphics and values.

2. MATERIALS AND METHODS

The experiments were carried out in the Hydraulic Laboratory of Bursa Technical University Department of Civil Engineering, using an open channel with 2.5 x 0.37 x 0.07m dimension (Figure 1). Three different slopes and flow rates were used in the experiment. The parameters used in this study were selected as the minimum, maximum, and average limits of the instruments in the lab and it was assumed that 3 points are enough to explain the linear or non-linear behaviour of the experiment. Observational cross section was selected through 1.10 m starting at 0.80 m distance from the upstream and ended in 0.60 m distance from the downstream of the channel; while the observations at the cross section were uniformed by the tailgate at the downstream of the channel. In such cases, this is the limitation of the study due to the experimental set.

Aggregated beds with four different grain diameters were used in the study and 9 experiments were carried out for each bed type. Therefore, this study also examines the behavior of the roughness coefficient in different slopes and bed conditions by a total 36 experimental data set. To do this, a steel wheel was used that can manually adjust the slope in the channel. In this respect, 0.0122, 0.0262 and 0.0402 channel bed slopes were used together with the combination of different bed material and flow rates in the experiments.

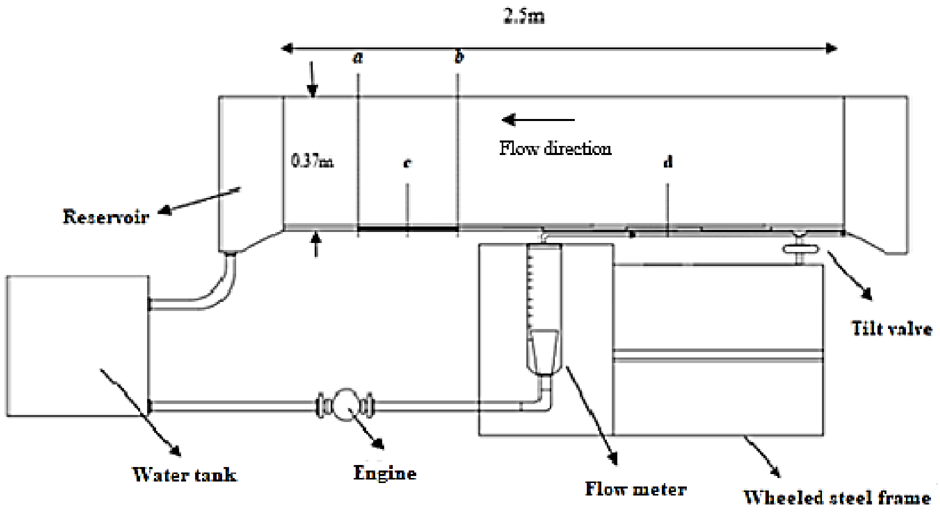


Figure 1:
Open channel section

As seen in Figure 1, the flow rates were kept constant at three values, 0.00305 m^3/s (Q_1), 0.0025 m^3/s (Q_2), and 0.0016 m^3/s (Q_3) with the help of a manually adjustable valve. Several blocks with 7×45cm dimensions are used to aggregate the different grain diameters that were glued on each block (Figure 2). The prepared blocks were placed in the channel bed between the location *a* and *b* (observational cross section) as shown in Figure 1, which was kept constant throughout the experiment. To prevent the block wall thickness from affecting the water level heights during the experiment, the empty blocks without any material along with the channel were arranged in the channel bed before and after the experimental block.

Figure 2:
Soil types with different particle size

Afterward, sieve analysis was performed for each grain size. As a result of the analysis, the particle diameter ranges of the aggregates in the GP (poorly graded) class are respectively, as shown in Figure 2; N1 range 25-19mm, N2 range 16-9.5mm, N3 range 9.5-2mm, and N4 range 2-0.106mm. The experiment started from the sample with the largest grain diameter and the other samples were used after the necessary measurements were taken. The pumping was started to discharge water from the tank of 80×70×45 cm dimensions that were located at the left side of the channel. The flow direction of the water in the channel is shown in Figure 1. To examine the change in water level, initially, the measurement was taken from the reference point *d* with a ruler and thus, the $h_{reference}$ values were collected from the *d* point and the h_{sample} values were collected from the *c* point during the experiment. Knowing the $h_{reference}$ value allows the water depth change to be observed on the block. In this way, the change in the manning coefficient without the sample ($h_{reference}$) after the sample is placed (h_{sample}) can be examined. In this respect, the Manning equation gives,

$$V = \frac{1}{n} R^{2/3} J^{1/2} \tag{1}$$

The velocity (V) obtained from Equation 1 is then inserted in Equation 2, which is the classical flow rate equation.

$$Q = VA \tag{2}$$

In these equations, Q (m^3/s) is the flow rate, A is the area (m^2), R is the hydraulic radius (m), J is the slope and n is the Manning roughness coefficient.

The Froude number, which is the main parameter in open channel flows, provides evidence for determination of the flow regime in the channel. In this context, it is possible to change the flow type in the experiments performed at different slopes and flow rates. Open channel flows are classified as critical, subcritical, and supercritical considering the dimensionless Froude number (Berkün, 2015) as

$$F_R = \frac{V}{\sqrt{gD}} \tag{3}$$

In this equation, V (m/s) represents the average velocity, g is the gravitational acceleration (m/s^2) and D (m) represents the hydraulic depth.

When the base and side walls of the channel are the same channel lining, the calculation of the roughness value can be obtained directly with the Manning equation (Djajadi, 2009). However, in the case of a composite channel, the composite roughness will be calculated (Khadka and Bhandari, 2022). When a culvert or channel section has different regions of roughness, the composite Manning's roughness coefficient must be calculated. Since roughness can vary significantly between surfaces in the same cross-section, it is necessary to determine a composite value for the cross-section (Chow 1959). The composite roughness is weighted based on the wetted perimeter associated with the different roughness segments. Therefore, the composite roughness changes with changes in water surface height. In this study, since the base and side walls of channel lining are different from each other, measuring the roughness only according to the type of the base may not give clear results. Hence, the differences created by the varying average roughness on different materials when considered in composite form should be taken into account. There are quite a variety of expressions available for obtaining the equivalent composite coefficient, n_c (Islam and Brown, 2013; Chow, 1959; Stephenson, 1981; Djajadi, 2009). Since expressions are produced within certain constraints, it can be said that an expression fits one model more and less fits the others (Djajadi, 2009). To be considered in this respect, the method suggested by Lotter (Lotter,1932) was also used in the study to alternate and confirm the results obtained by the Manning method as,

$$n_{c}=\frac{P\times R^{5/3}}{\left(\frac{P_1R_1^{5/3}}{n_1}+\frac{P_2R_2^{5/3}}{n_2}+\cdots+\frac{P_NR_N^{5/3}}{n_{1N}}\right)} \tag{4}$$

where, n_c is the composite Manning's Roughness Coefficient; P is the wetted perimeter; R is the hydraulic radius; n is the Manning's Roughness Coefficient and N is the subscripts denoting individual subareas of the entire compound channel section

If, Fr=1 then it is critical flow; if Fr < 1 it is a subcritical flow while such flows are also called "subcritical flow" or "stagnant flow" due to the small velocity. Finally, if Fr > 1, it is called as a supercritical flow (Chow, 1959).

2. RESULTS

2.1. Relationship Between Flow Rate and Roughness Coefficient

In Figure 3, the relationship between flow rate and roughness coefficients in the experiments with four different grain size and three different slopes is given. In similar experimental studies, it has been determined that flow rate and roughness coefficient have a negative correlation at a certain slope value (Gautam, 2021; Jarrett, 1985; Ibrahim and Abdel-Mageed, 2014). In light of this information, three different slopes were taken into account as a result of 12 tests, and as the roughness coefficient increases, the flow velocity in the channel decreases, and the flow values decrease with the reduction of the speed.

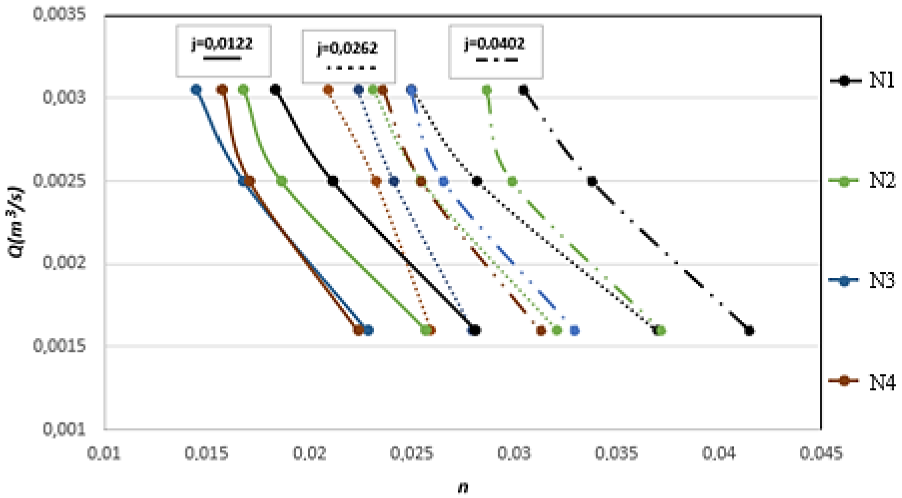
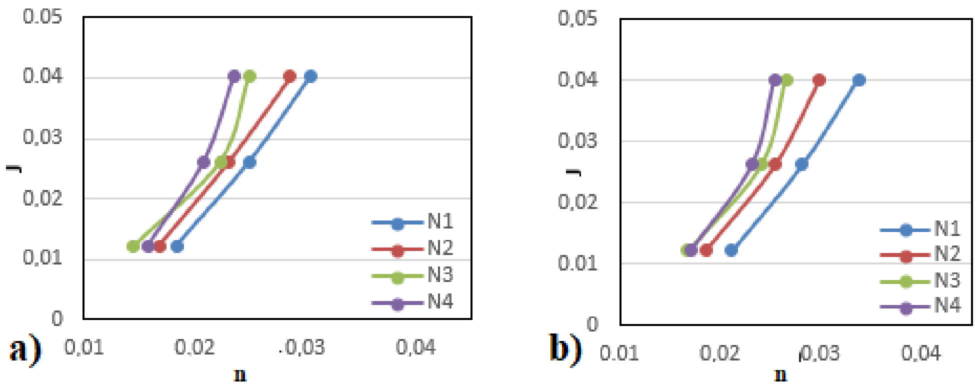


Figure 3:
Relationship between flow rate and roughness coefficient

2.2. Relationship Between Slope and Roughness Coefficient

Figure 4 shows the graphs given for the channel slope against the roughness coefficient. These graphs were repeated at different flow rates and different soil samples. In the study of Merry (2017), with two different slopes it was concluded that the roughness coefficient of the channel with 1:200 slope is higher than the roughness coefficient of the channel with 1:500 slope. In this study as given in Figure 4a, 4b and 4c, as the slope increases, the roughness coefficient is expected to increase at a certain flow rate. In addition, Hessel et al., (2003) field experiment gives similar results. In the study, the effect of the slope on the manning coefficient was investigated by using the 6-64% slope of the Chinese Loess Plateau. As a result, it was determined that the roughness coefficient increased linearly with the increase of the slope. When the graphs are compared, it has been determined that the Manning roughness coefficient on the x-axis increases as the flow rate decreases, and the slope values increase in direct proportion to the roughness coefficient.



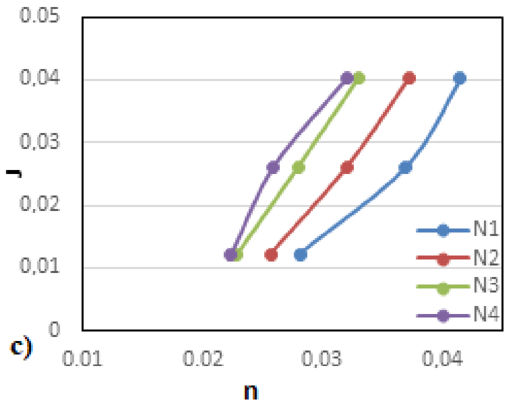


Figure 4:
Slope and roughness coefficient relationship graph for a) Q_1=0.00305m^3/s b) Q_2=0.0025 m^3/s and c) Q_3=0.0016 m^3/s

3.3. Soil Samples and Roughness Coefficient

In the experiments, the effect of four different soil samples on the roughness coefficient was also examined (Figure 5). The relationship determined at a certain slope value from sample 1, where the grain diameter is the highest, to sample 4, where it is the smallest, is given below. The study was based on the d_{50} median grain size of the samples. The grain distribution curve was drawn as d_{50}= 28mm for N1, d_{50}= 17.5 mm for N2, d_{50}=4mm for N3, and d_{50}=1.75 mm for N4.

Lau and Afshar (2013) stated in their studies that the roughness coefficient was higher than the smooth one of the experiment with rough bed material. Furthermore, in the laboratory study of Sawant et al., (2020), similar to the present study, the value of the Manning roughness coefficient was found to increase with increasing bed material size for each channel base slope and flow rate combination. When the graph was examined, it was observed that the roughness coefficient increased when the median grain size increased at a certain slope value.

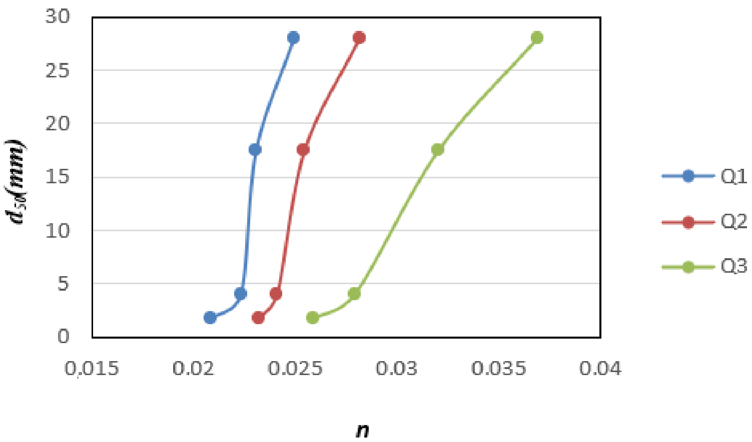


Figure 5:
The relationship between the roughness coefficient of soils with different flow rates and the median grain size

In this respect, Table 1 details the 36 experiments performed in the study. The discharge rates *Q*, horizontal bed slope *J*, and obtained roughness coefficients *n* are all given up to 4 decimal places. As can be seen from the table when *Q* (m^3/s) and *J* are fixed the larger grain size results in higher amount of *n* (roughness). When the slope increases, *n* also experience an increase. But the discharge rate and roughness behave in different way.

Table 1. Experiment summary table

Sample	**1**			**2**			**3**			**4**		
Q *(m^3/s)*	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016	0.0031 0.0025 0.0016
J (-)	0.0122	0.0262	0.0402	0.0122	0.0262	0.0402	0.0122	0.0262	0.0402	0.0122	0.0262	0.0402
n (-)	0.0183 0.0211 0.0281	0.0249 0.0282 0.0369	0.0305 0.0338 0.0415	0.0168 0.0186 0.0257	0.0231 0.0255 0.0321	0.0286 0.0299 0.0372	0.0145 0.0168 0.0228	0.0229 0.0241 0.0279	0.0249 0.0265 0.0329	0.01576 0.01706 0.02236	0.0209 0.0232 0.0259	0.0236 0.0254 0.0313
h (m)	0.085 0.081 0.071	0.080 0.075 0.065	0.079 0.073 0.060	0.079 0.073 0.066	0.075 0.069 0.058	0.075 0.066 0.055	0.070 0.067 0.060	0.073 0.066 0.052	0.067 0.060 0.050	0.075 0.068 0.059	0.069 0.064 0.049	0.064 0.058 0.048

3.4. Froude Number

Since the roughness coefficient is affected by the changing flow type, in Figure 6, the relationship between roughness coefficient and Froude number for different soil types, flow rates, and slopes has been examined and flow types have been determined for each parameter. If the Froude number is less than 1, the effect of the subcritical regime continued throughout the experiment. In the experiment consisting of 32 tests, it was determined that the Froude number ranged 0.38-0.86. In Al- adili et al., (2005) study, the relationship between Froude number and the roughness coefficient of the channel, which has different slopes, was investigated through field experiment. Similar to the current study, the Froude number and the Manning roughness coefficient turned out to be an inverse relationship with a good agreement for subcritical flow. In addition, when the graphs are compared, a noticeable increase observed in the Froude number occurs with the increase of the slope, similar to the Ahmad et al., (2017) study. When the slope values are correlated with Froude number values, the Froude number range for J_1 (=0.0122) is 0.38-0.75, while for J_2 (=0.0262) is 0.44-0.76, and for J_3 (=0.0402) is 0.49-0.86. In this case, the increase in the slope brings the Froude number closer to 1 and causes the effect of the subcritical regime to progress by decreasing. In addition, when the graphs are compared, it is seen that for the given slope, the Froude number decreases proportionally as grain size increases (Figure 6a, 6b and 6c).

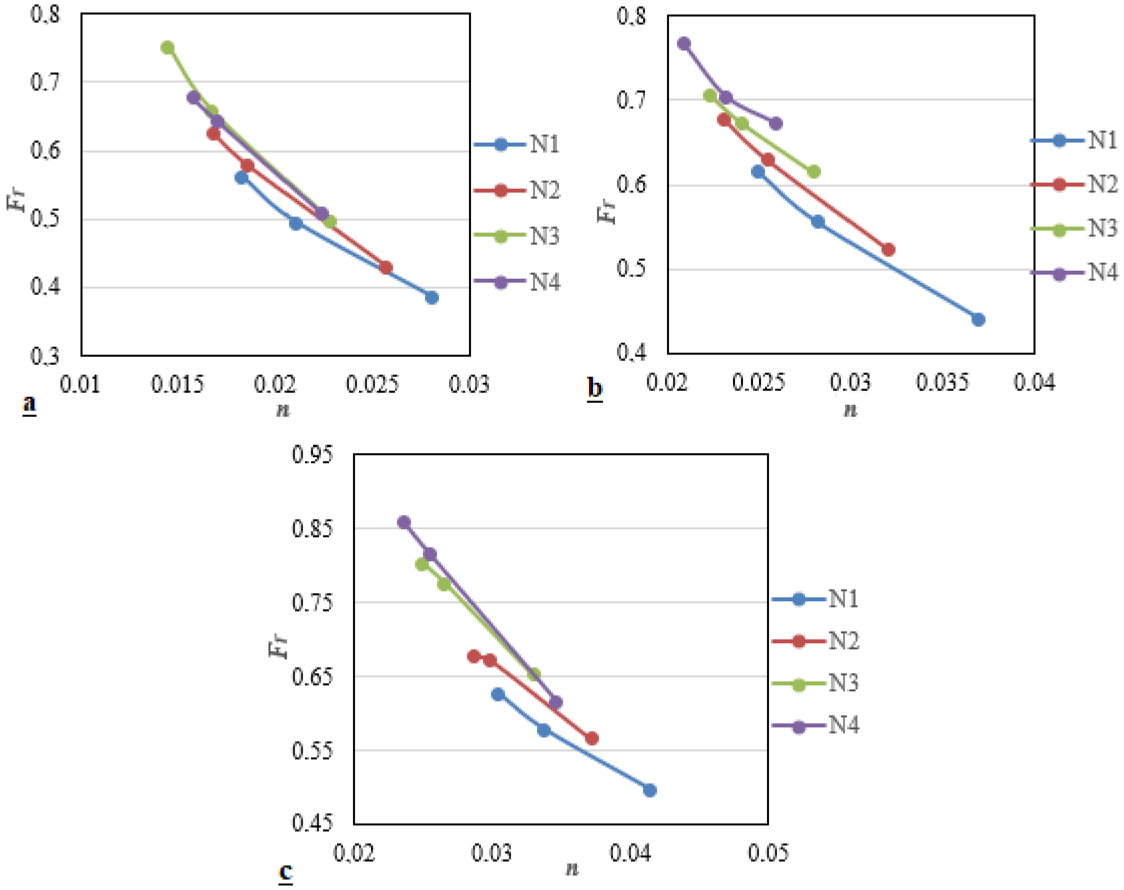


Figure 6:
Froude number and Manning roughness coefficient relationship graph for a) J_1=0.0122 b) J_2=0.0262 and c) J_3=0.0402

3.5. Lotter Formula vs Manning Equation

The roughness values were then obtained using the Manning equation (Table 1). These results are mostly accepted when the side walls and base of channel lining are made of the same material. However, in this study, the side walls were made up of Plexiglass, while the base was made up with steel lining. The average of the Manning coefficients obtained for each condition was then calculated as 0.026. As detailed before, the Lotter equation was also applied to compare the validity of the results obtained by the Manning equation. Eventually, the roughness coefficient value (n_c) based on wetted perimeter (P) and hydraulic radius (R) was calculated as 0.033. This situation shows that there is no definite method of choosing the value of n, as Chow (1959) stated. Choosing n, precisely means estimating the resistance to flow in a given channel, and this estimation is a rather intangibles matter. The value of n, which will give different results if different parameters are included, will also not give the same result using different methods. In this case, studies which using different parameters, models and methods will contribute to the literature and improve the roughness coefficient estimation.

4. CONCLUSION

The determination of the roughness coefficient in the Manning equation, which is frequently used in open channel flows, varies depending on many parameters. Knowing both the channel and flow characteristics is very important in terms of determining the coefficient. In this study, the relationship of the roughness coefficient with channel slope, grain diameter and different flow rates is examined with the help of graphs derived from 36 experimental data.

As a result of laboratory studies, it was seen that in a channel with the same slope, the flow rate and the roughness coefficient are inversely proportional. Also, at a certain slope value, it was observed that the roughness coefficient increased as the median particle size increased. The slope values increased in direct proportion to the roughness coefficient in the experiments with the same flow rate. It was also determined that the Froude number ranged from 0.38 to 0.86. In the subcritical flow regime, the Froude number and the roughness coefficient show an inverse correlation for the same slope. In addition, as the slope increases, Froude number and the roughness coefficient increase for the same grain size. While it is seen that the n varies between 0.020-0.028 according to the condition of the material (soil-gravel) and conditions in the channel, it is seen that the n value takes values between 0.0145-0.415 as the results of our study.

Alternatively, the Lotter method is used since the channel used in the experiments was made of composite material. The roughness values obtained by Lotter method was then used to confirm the validity of the Manning roughness coefficients. As a result, a 0.007 difference was observed between the roughness coefficient obtained by the Manning and Lotter methods. The reason of this small difference is the effect of the side walls and composite materials which is neglected in Manning equation. As each method attaches importance to different criteria, the roughness coefficient value also changes according to these, and thus increase in studies about this field helps to obtain this coefficient properly. The correct selection of the roughness coefficient will affect the velocity and the water level that will occur in the sections. Therefore, the importance of the roughness coefficient increases much more in flood times. Hence, in order to be protected from the floods, correct project planning and design is very important.

CONFLICT OF INTEREST

The authors acknowledge that there is no known conflict of interest or common interest with any institution / organization or person.

AUTHOR CONTRIBUTION

Damla Yılmaz organized the data collection and processing in the laboratory study. Egemen Aras determined and interpreted the conceptual process of the study. Babak Vaheddoost analyzed and interpreted the data. All authors contributed to the final version of the manuscript.

REFERENCES

1. Abd Wahıd, N.L.A.B. (2015) Impacts of vegetation on the characteristics of the flow: Manning Roughness Coefficients For Open Channel, *Final Year Project Report*,Universiti Teknologi Petronas, Civil Engineering.

2. Abood, M. M., Yusuf, B., Mohammed, T. A., & Ghazali, A. H. (2006). Manning roughness coefficient for grass-lined channel. *Journal of Science and Technology*, *13*(4), 317-330.

3. Ahmad, N.A., Saiful Bahry, S.I., Ali, M.Z., Daud, M.M.A., , and Musa, S. (2017) Effect of flow resistance in open rectangular channel, *MATEC Web of Conferences* 97, 01107. Doi: 10.1051/matecconf/20179701107

4. Al-Adili, A., Sadiq, A., & Faroq, F. A. D. I. A. (2005). Study For The Effect of Manning Roughness on Froude number in open channel (subcritical flow). *Engineering and Technology Journal, University of Technology*, *33*(5), 1164-1177. Doi: 10.30684/etj.33.5A.12

5. Berkün, M. (2015). *Akışkanlar Mekaniği ve Hidrolik*: Açık kanallarda uniform akım, Literatür Yayıncılık, İstanbul.

6. Chow, V. T. (1959) *Open Channel Hydraulics*. McGraw-Hill, New York

7. De Doncker, L., Troch, P., Verhoeven, R., Bal, K., Meire, P., & Quintelier, J. (2009). Determination of the Manning roughness coefficient influenced by vegetation in the river Aa and Biebrza river. *Environmental fluid mechanics*, *9*(5), 549-567. Doi: 10.1007/s10652-009-9149-0

8. Djajadi, R. (2009). Comparative study of equivalent Manning roughness coefficient for channel with composite roughness. *Civil Engineering Dimension*, *11*(2), 113-118. Doi: 10.9744/CED.11.2.PP.

9. Gautam, A. (2021) Determination of manning's roughness coefficient in bijayapur irrigation canal, Kaski, Nepal, *Himalayan Journal of Applied Science and Engineering (HiJASE*), Vol. 2, Issue 2, Nov. Doi: 10.1007/s10652-009-9149-0

10. Hessel, R., Jetten, V., & Guanghui, Z. (2003). Estimating Manning's n for steep slopes. *Catena*, *54*(1-2), 77-91. Doi: 10.1016/S0341-8162(03)00058-4

11. Islam, J. & Brown, N. (2013). Compound Channel Modellıng Capabılıty Assessment Of 1D Hydraulic Model, Water New Zealand Storm water Conference.

12. Khadka, D. B., & Bhandari, P. (2022). Effects of Bed Materials to Flow Characteristics on Open Channel and Gradually Varied Flow Simulation Using Genetic Algorithm (GA). European Journal of Applied Sciences, 10(4). 1-20. Doi: 10.14738/aivp.104.12709

13. Lau, T.W. and Afshar, N.R. (2013) Effect of roughness on discharge, *UNIMAS e-Journal Civil Engineering*: Volume 4, Issue 3. Doi: 10.33736/jcest.124.2013

14. Lotter, G. K., Considerations on Hydraulic Design of Channels with Different Roughness of Walls, Transactions of All-Union Scientific Research Institute of Hydraulic Engineering, Vol. 7, 1932, pp. 55-88.

15. Merry, A. M. (2017) Experimental study for determine manning's coefficient with different slopes and channel bed materials, *Kufa Journal of Engineering* Vol. 8, No. 3, P.P. 76-88. Doi: 10.30572/2018/KJE/8031160

16. M.M. Ibrahim, Neveen B. Abdel-Mageed. (2014) Effect of bed roughness on flow characteristics. *International Journal Of Academic Research Part A*; 6(5), 169-178. doi: 10.7813/2075-4124.2014/6-5/A.24

17. R. D. Jarrett. (1985) Determination of roughness coefficients for streams in Colorado, U.S. *Geological survey*, Lakewood, Colorado. Doi: 10.3133/wri854004

18. Sawant, P.N., Kumar, A., and Nivesh, S. (2020) Flume experiment for evaluation of effect of different bed conditions on Manning's roughness coefficient in open channel flow, *Indian Journal of Soil Conservation*, Vol 48, No,2(125-130).

19. Stephenson, D., Stormwater Hydrology and Drainage, Development in Water Science, Vol. 14, Elsevier, Amsterdam, 1981, pp. 276-287.

20. Yerdelen, C., Mertsoy, M., and Tayfur, G. (2015) Rijit gövdeli bitkilerin neden olduğu manning katsayısının araştırılması, *İMO Teknik Dergi*, 7055-7076, Yazı 433.

21. Wu Fu-Sheng. (2008) Characterıstıcs of flow resistance in open channels with Non-Submerged rigid vegetation, *Journal Of Hydrodynamics*. 2008,20(2):239-245. Doi: 10.1016/S1001-6058(08)60052-9