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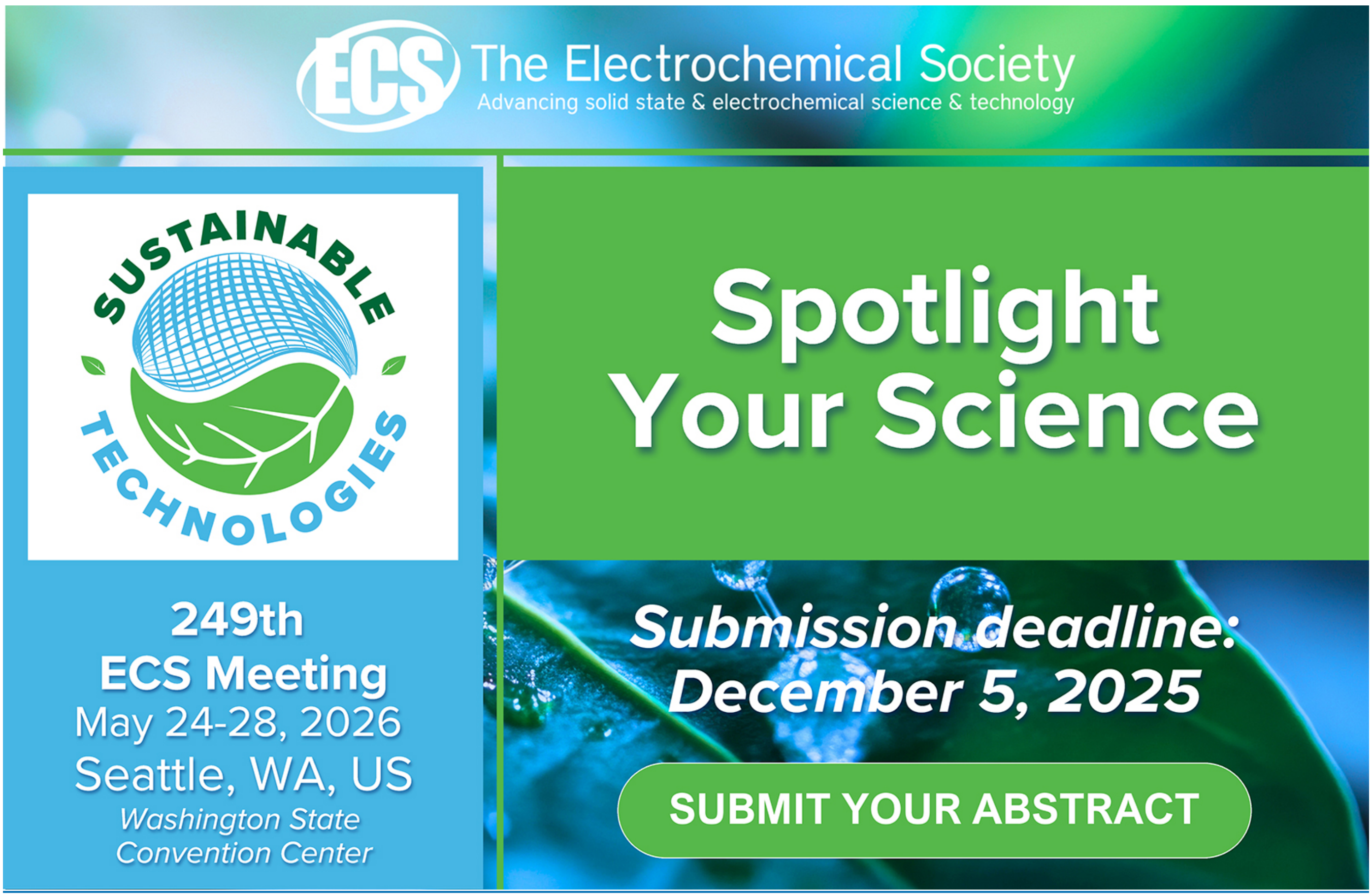

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Measurement of Turbulent Flows and Shear Stress on Open Channels

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Abstract. The phenomenon of turbulent flows becomes a virtual object in any changes in open channel flow hydraulics. Turbulent flow and shear stress have a role in the geometrical changes of bed channel and sediment movement. The dynamics of turbulent flow are consequences of hydraulic channel dynamics. Turbulent flow has excessive kinetic energy resulting in resistance force because the increase of friction effect and infraction in turbulent flow creates a complex phenomenon. Shear stress is in the eternal pressure of flow against the deformation of the primary basic form of channel. The research aims to analyze turbulent flow, shear stress, and bed scours ' phenomena and potential. Measurement of turbulent flows is by measuring the flow velocity in four segments at a distance of 100 cm each. The channel's cross-section is divided into nine parts and five measurement points in the flow depth of inner and outer regions. There are three variations of channel discharge and slope, i.e., low discharge (Q1), medium discharge (Q2), large discharge (Q3), and downward slope (S1), medium slope (S2), and high pitch (S3). The parameter of turbulent flow analysis, shear stress includes flow velocity average (U), flow depth (h), channel slope (S), viscosity (φ), the mass density of the liquid (ρ), the characteristic length or hydraulic radius (L/R) by using an empirical equation approach. Turbulent flow analysis used dimensionless Reynolds' number equation approach. The effect of hydrodynamic on turbulent flow causes the distribution of shear and scour stress, transport, and sediment deposition. The increase in the slope of the channel affects the increase in the values of shear stress.

1. Introduction

Turbulent flow is a flow characteristic that occurs both in open and closed channels, and it creates a separate phenomenon in channel hydraulics. Turbulent flow causes problems at the bed and channel slope that triggers changes in the channel to each shift in turbulent flow and shear stress. It is interesting to observe the parameters that contribute to turbulent flow and shear stress by making direct measurements on the open channel to obtain the phenomena.

Research on Reynolds' shear stress has been conducted with various types of channel or river bed materials to date, including the effect of adding large rock base materials on turbulent flow characteristics [1] , the spread of large rock have a small impact on the magnitude of the base flow velocity (stream wise), but tends to reduce the gradient of velocity in near-bed, thereby affecting the bed shear stress [2] , the effect of rock spacing and the ratio of sub-merge of the rock on the bed shear stress on the gravel-bottom flume [3] , direct measurement of the bed shear stress [4][5], the massive rock or boulders affect the average and turbulent flow characteristics [6][7] , the bed channel with the spatial variability of the boulders at the bed shear stress [8][9] , the bed roughness, the shear stress variability [10], the bed channel slope affects the increase in the values of shear stress [4] [11] , the distribution of Reynolds' shear stress, the area near the bed and the inner side of the bend has a more excellent value [12].

Research on turbulent flow as a trigger for scouring due to shear stress, among others, the phenomenon of turbulent flow [13][14], turbulent flow affects the bottom's transport. Elevated sediments [2] Bend in 650 in the upstream channel affects the distribution of velocity and shear stress in the channel bend [12], flow characteristics contribute significantly to sediment erosion and deposition [8], turbulence intensity and average velocity occur due to the habitat selection parameters of the channel conditions [1]. Turbulent flow eddies are evenly distributed to the two boundary sections [15]. Denser boulders contribute to a more uniform contribution of turbulent flow events (Reynolds) and shear stress [16], building models contribute significantly to increasing the total flow of turbulent kinetic energy [11]. The groin on the channel bends causes new turbulence flow phenomena, shear stresses, and local scouring [17]. However, it is still necessary to vary the turbulent flow contribution pattern and shear stress for some raw materials for channels or rivers.

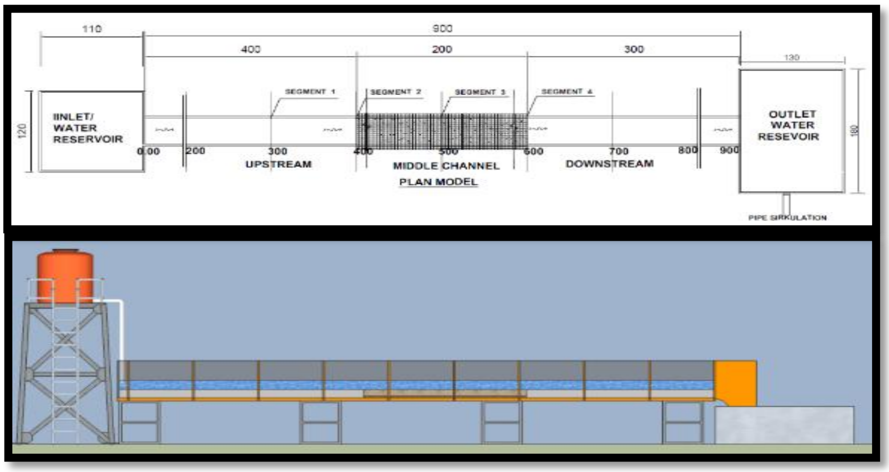
Curing time has a significant effect on the increase of the compressive strength test of the clay soil. [18], the wave reflection coefficient decreases with the rise of wave steepness [19], Effect of Froude Number, the smaller the scour depth that occurs [20], The pattern of sediment movement happening in the BiliBili Reservoir [21]. The more significant the Froude number causes, the greater the scour depth [22].

The research was conducted to improve understanding of the role of turbulent flow and shear stress. The study's objective is to analyze the turbulent flow, shear stress, and the phenomena and potential of bed scour. The problem of turbulent flow becomes a particular problem in river hydraulics and bed shear stress.

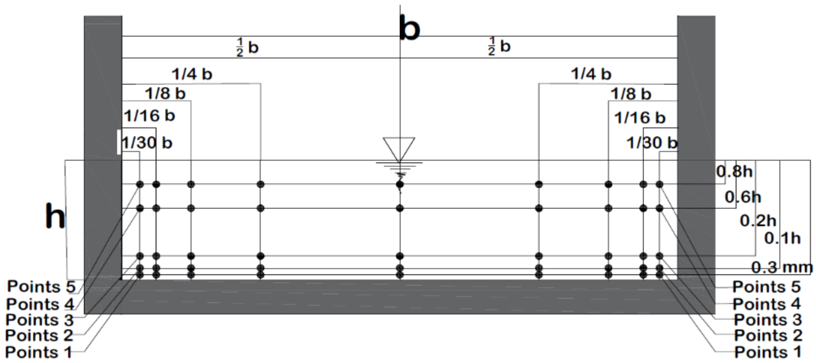
2. Method and Material

2.1. Preparation of tools and materials

The testing was carried out in the hydraulics laboratory of Hasanuddin University, Faculty of Engineering. It is conducted between May and July 2020 by using a channel flume, (b) 35 cm in width, (h) 45 cm in height, (L) 900 cm in length, and equipped with a pump, inlet, and outlet reservoir as shown in Figures 1 and 2.



Figures 1. The layout of the channel model



Figures 2. Scheme of detailed points measurement velocity

It was carried out by laboratory experiments on observations under artificial conditions to investigate the relationship between variables gives specification treatments to several experimental groups with a control comparison.

2.2. Measurement of flow velocity and data validation

Flow velocity is an essential factor in the turbulent flow that can increase the velocity and shear stress. The data of flow velocity and height become the primary data of this research. Measurement of velocity distribution in the inner region or near-bed and outer region or far-bed channel [23]. Measurement of turbulent flow is done by measuring flow velocity in four segments with a distance of 100 cm each, i.e., the upstream, middle, and downstream channels. The channel's cross-section is divided into nine sections, 1/30 b, 1/16 b, 1/8 b, ¼ b, ½ b, and five measurement points at flow depth, channel 0.3 cm, 0.1 h, 0.2 h, 0.6 h, 0.8 h (cm). There are three variations of discharge and channel slope, i.e., low, medium, and high discharge, and downward slope, (S1) medium slope (S2), high slope (S3). The tool used in measuring flow velocity is a portable automatic Pitot by the following equation:

$$u = \sqrt{4.24\,\Delta h} \quad \text{(m/dt)} \quad (1)$$

$$U = \frac{1}{n}\,.R^{2/3}.S^{1/2} \quad \text{(m/dt)} \quad (2)$$

$$U = C\sqrt{R.S} \quad \text{(m/dt)} \quad (3)$$

2.3. Data Analysis Parameter

The parameters used in analyzing turbulent flow, stress, and shear velocity were bottom flow velocity (u), near-surface flow velocity (U), flow velocity inner region or near-bed (u) flow depth (h), and channel slope (S), viscosity (φ), the mass density of the liquid (ρ), the characteristic length or hydraulic radius (L/R) by using an empirical equation approach. The dimensionless variables used for the classification of Reynolds' number (Re) as follows:

$$R_e = \frac{\rho U R}{\mu} \quad (4)$$

The turbulent flow shear stress (τ_t) [4] can be calculated by using the following equation:

$$\tau_t = \rho w\,.\,g\,.\,R.\,S \text{ or } \tau_t = = \rho_w.u_*^2 \text{ and} \quad (5)$$

$$u_* = \sqrt{g.R\,.S} \quad (6)$$

The bed shear stress (τ_o) can be calculated by using the following equation:

$$\tau_o = \rho w.g.h.S \quad (7)$$

3. Results and Discussions

3.1. Analysis of Flow Characteristics based on Reynolds' Number and Shear Stress

According to Richard Feynman, the flow characteristics are a separate phenomenon in a flow system and the part of flow dynamics of the channel, who is describing the turbulence of flow until now has not been resolved in classical physics. Turbulent flow occurs because it is dominated by inertia, while the dominant viscosity force that occurs is laminar flow. The turbulent flow measurement in the outer region or far-bed of the channel in four segments, i.e., upstream, middle 1, middle two, and downstream, and the turbulent flow calculation are described in Tables 1, 2, 3, and 4.

Table 1. Calculation of flow characteristics based on the Reynolds' number in the upstream segment

Scenario	Discharge (m^3/dt)	S (%)	U (m/dt)	Re	τ_t (kg/m^2)	τ_o (kg/m^2)	u_* (m/dt)
$TKTSQ_1S_1$	0.00871	0.00056	0.3160	3,003.84	0.000801	0.000128	0.028466
$TKTSQ_1S_2$	0.00871	0.00189	0.3189	2,816.76	0.002122	0.000341	0.046339
$TKTSQ_1S_3$	0.00871	0.00267	0.3377	2,809.54	0.002769	0.000444	0.052940
$TKTSQ_2S_1$	0.00982	0.00056	0.3198	3,145.12	0.000801	0.000131	0.028474
$TKTSQ_2S_2$	0.00982	0.00189	0.3297	2,901.04	0.002140	0.000353	0.046540
$TKTSQ_2S_3$	0.00982	0.00267	0.3414	2,816,60	0.002747	0.000455	0.052724
$TKTSQ_3S_1$	0.01011	0.00056	0.3252	3,225.39	0.000802	0.000135	0.028483
$TKTSQ_3S_2$	0.01011	0.00189	0.3353	2,969.12	0.002082	0.000353	0.045903
$TKTSQ_3S_3$	0.01011	0.00267	0.3457	2,934.06	0.002725	0.000464	0.052519

Table 2. Calculation of flow characteristics based on the Reynolds' number in the middle one segment

Scenario	Discharge (m^3/dt)	S (%)	U (m/dt)	Re	τ_t (kg/m^2)	τ_o (kg/m^2)	u_* (m/dt)
$TKTSQ_1S_1$	0.00871	0.00056	0.3147	3,031.54	0.000801	0.0001277	0.028466
$TKTSQ_1S_2$	0.00871	0.00189	0.3244	2,860.12	0.002122	0.0003409	0.046339
$TKTSQ_1S_3$	0.00871	0.00267	0.3364	2,794.34	0.002769	0.0004110	0.052940
$TKTSQ_2S_1$	0.00982	0.00056	0.3189	3,161.76	0.002140	0.0003533	0.046540
$TKTSQ_2S_2$	0.00982	0.00189	0.3290	2,927.87	0.002140	0.0003533	0.046540
$TKTSQ_2S_3$	0.00982	0.00267	0.3436	2,905.50	0.002746	0.0004549	0.052724
$TKTSQ_3S_1$	0.01011	0.00056	0.3255	3,281.49	0.000790	0.0001332	0.028284
$TKTSQ_3S_2$	0.01011	0.00189	0.3352	2,982.26	0.002082	0.0003533	0.045903
$TKTSQ_3S_3$	0.01011	0.00267	0.3479	2,739.93	0.002725	0.0004549	0.052519

Table 3. Calculation of flow characteristics based on the Reynolds' number in the middle two segments

Scenario	Discharge (m^3/dt)	S (%)	U (m/dt)	Re	τ_t (kg/m^2)	τ_o (kg/m^2)	u_* (m/dt)
$TKTSQ_1S_1$	0.00871	0.00056	0.3161	3,005.72	0.0008001	0.0001241	0.0284656
$TKTSQ_1S_2$	0.00871	0.00189	0.3333	2,944.47	0.0021215	0.0003596	0.0463386
$TKTSQ_1S_3$	0.00871	0.00267	0.3363	2,932.11	0.0027690	0.0004549	0.0529400
$TKTSQ_2S_1$	0.00982	0.00056	0.3183	3,153.49	0.0008011	0.0001314	0.0284744
$TKTSQ_2S_2$	0.00982	0.00189	0.3268	2,406.34	0.0021400	0.0003533	0.0465401
$TKTSQ_2S_3$	0.00982	0.00267	0.3442	2,993.52	0.0027465	0.0004549	0.0527244
$TKTSQ_3S_1$	0.01011	0.00056	0.3253	3,269.30	0.0018553	0.0003331	0.0427277
$TKTSQ_3S_2$	0.01011	0.00189	0.3344	2,869.13	0.0020818	0.0003845	0.0459027
$TKTSQ_3S_3$	0.01011	0.00267	0.3518	2,622.68	0.0011855	0.0004373	0.0332764

Turbulent flow occurs because the flow particles move in an irregular path, both in terms of space and time, to meet the turbulent flow requirements. Turbulent flow is influenced by inertia and viscosity. The bed shear stress calculation is done in the inner region, or near-bed, while in the outer area or far-bed the channel for the analysis for turbulent shear stress. Shear stress is influenced by several factors such as water density, gravitational, flow height, hydraulic radius as characteristic length.

Table 4. Calculation of flow characteristics based on the Reynolds' number in the downstream segment

Scenario	Discharge (m^3/dt)	S (%)	U (m/dt)	Re	τ_t (kg/m^2)	τ_o (kg/m^2)	u_* (m/dt)
$TKTSQ_1S_1$	0.00871	0.00056	0.3155	3,008.61	0.0008006	0.0001241	0.0284656
$TKTSQ_1S_2$	0.00871	0.00189	0.3254	2,880.33	0.0021215	0.0003596	0.0463386
$TKTSQ_1S_3$	0.00871	0.00267	0.3392	2,858.03	0.0027690	0.0004110	0.0529400
$TKTSQ_2S_1$	0.00982	0.00056	0.3193	3,169.63	0.0008011	0.0001314	0.0284744
$TKTSQ_2S_2$	0.00982	0.00189	0.3269	2,879.95	0.0022140	0.0003720	0.0465401
$TKTSQ_2S_3$	0.00982	0.00267	0.3451	2,789.65	0.0027465	0.0004549	0.0527244
$TKTSQ_3S_1$	0.01011	0.00056	0.3252	3,425.96	0.0007570	0.0001277	0.0276804
$TKTSQ_3S_2$	0.01011	0.00189	0.3279	3,239.34	0.0020818	0.0003845	0.0459027
$TKTSQ_3S_3$	0.01011	0.00267	0.3538	3,131.87	0.0027252	0.0004285	0.0525198

3.2. *Effect of Discharge, Slope on Turbulent Flow and Shear Stress*

Flow dynamics, as occurred in open channels, cause complex geometrical changes and be part of channel dynamics. Changes in flow parameters, such as flow velocity, slope, and hydraulic radius, lead to channel dynamics. This dynamic affects other flow parameters, i.e., acceleration, turbulent flow, bed shear stress, and turbulent shear stress. The flow velocity distribution in the open channel is influenced by the channel's slope and the necessary roughness factor, and the channel walls.

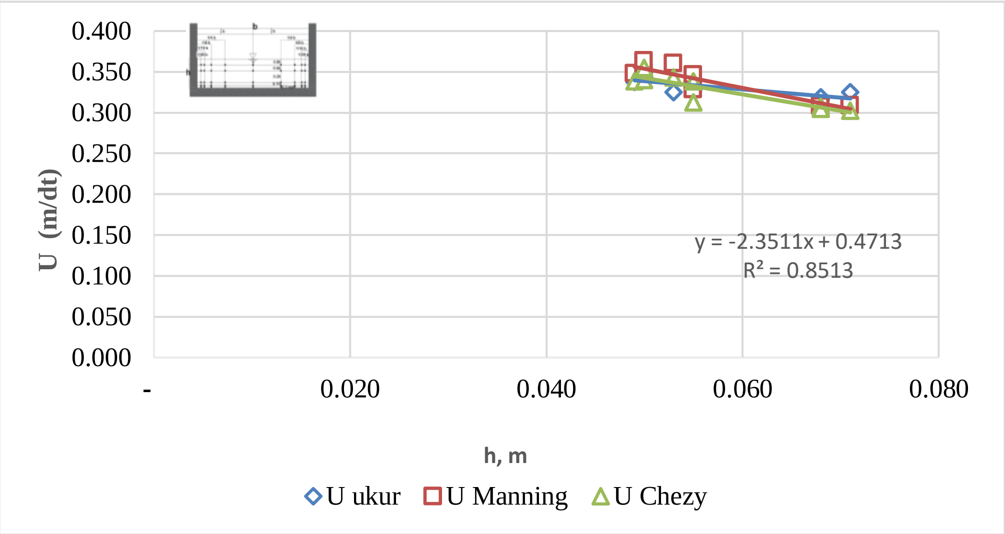


Figure 3. Relationship between discharge with velocity flow

Figure 3 shows the change in flow velocity as the flow height increases. Direct measurement of flow velocity in open channels is validated by empirical equations, namely Manning and Chezy, showing a trend or similarity inflow velocity changes. These results show three variations of discharge, namely low discharge (Q1), medium discharge (Q2), high discharge (Q3), and three types of channel slope variations, namely, downward channel slope (S1), medium channel slope (S2), high channel slope. (S3) results in a change in flow height. Changes in increasing flow velocity along with changes in flow height with decreasing flow height (h) cause the flow velocity to be more significant.

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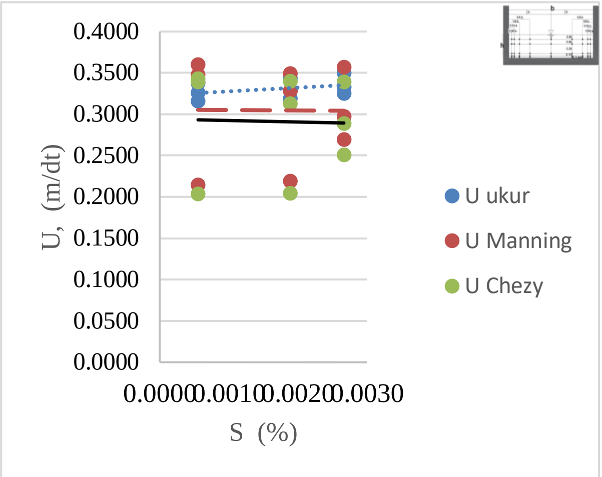


Figure 4. Relationship between slope of the bottom of the channel with velocity flow

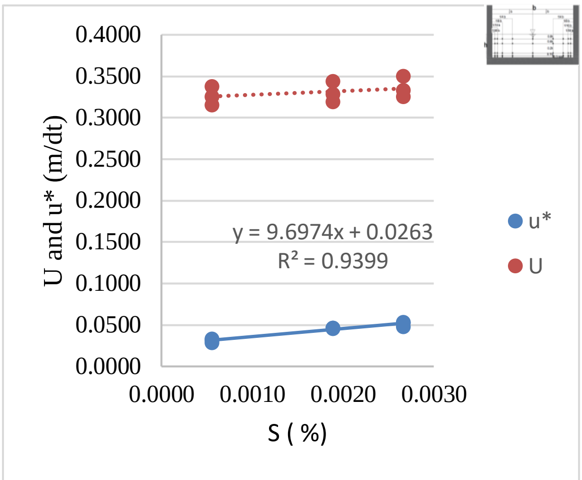


Figure 5. Relationship between bed slope of the cannel with flow velocity and shear velocity

Figure 4 shows the channel's bottom slope's variation with direct measurements on the open channel having a trend or similarity in the change in flow velocity with the empirical equation, namely, Manning and Chezy. Figure 5 shows that the difference in chanbottom's slopebottom's slope affects the flow velocity and shear speed due to the greater slope of the channel bottom. Increasing the shannel bedchannellope and slope increase in turbulent kinetic energy [11].

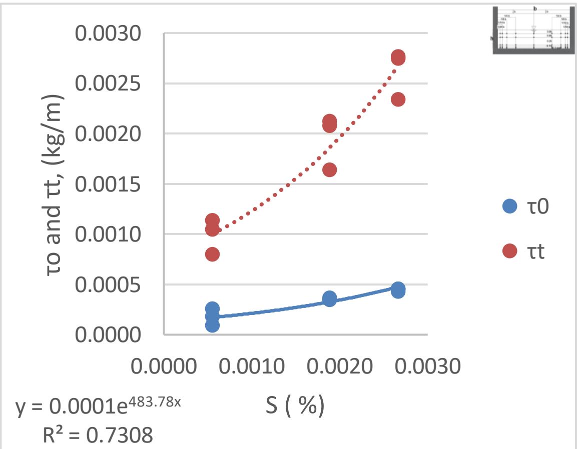


Figure 6. Relationship between slope of the bottom of the channel and with bed shear stress (τ_o) and turbulent shear stress (τ_t)

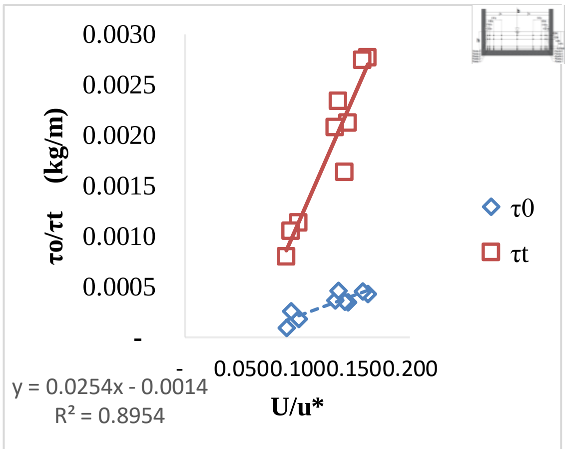
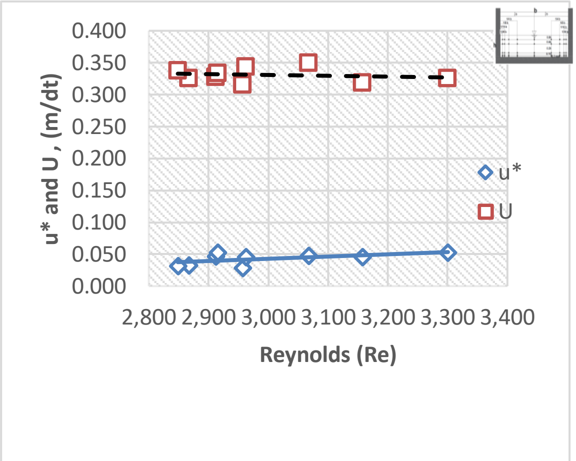
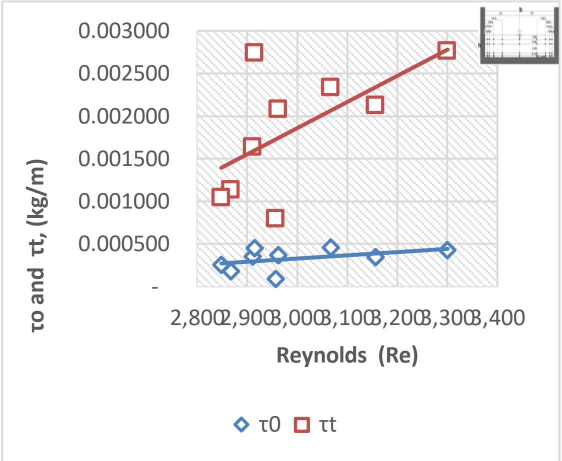


Figure 7. Relationship between non dimensional velocity flow and shear stress

Figure 6 shows the increase in the value of the bed shear stress (τ_o) influenced by the channel slope, flow depth, and gravity. Meanwhile, the turbulent shear stress (τ_t) is controlled by the slope of the channel, the hydraulic radius as a characteristic length [6][7], and gravity, which is dominated by the inertia force. Whereas in Figure 7 shows the increase influences the change in bed shear stress (τo) and turbulent shear stress (τt) inflow velocity and shear velocity, and the base slope of the channel affects the increase in the value of shear stress [11] [4].



Gambar 8. Relationship between of Reynolds number (Re) with shear velocity (u_*) and flow velocity (U)



Gambar 9. Relationship between of Reynolds number (Re) with bed shear stress (τ_o) and turbulent shear stress (τ_t)

Figure 8 shows that the increase in flow velocity and shear velocity is directly proportional to the Reynolds number. The greater the Reynolds number value due to the increase in flow velocity and the greater the shear velocity. Meanwhile, Figure 9 shows the increase in flow turbulence affects changes in shear stress and flow rate. The increase in the Reynolds number affects the turbulent kinetic energy flow so that the potential for scouring and transport of elevated and bottom sediments [2] [13] [14].

4. Conclusion

The results of the analyzed discussion of the main variables of turbulent flow and shear stress can be concluded as follows:

1. The increasing value of turbulent flow is directly proportional to the flow velocity, Viscocity, and hydraulic radius as the characteristic length.
2. Turbulent flow is dominated by inertia force with kinetic energy, which causes the bed channel's stability to be disturbed due to the scouring of the bed and elevated sediments.
3. The bed shear stress is influenced by the slope, gravitational, and flow depth, causing the disturbance of bed stability.
4. Turbulent shear stress is influenced by the channel slope, hydraulic radius, and gravity, causing bed stability disturbance.

5. Suggestions

The results of observation and analysis for several problems become important topics for further researches, including:

1. It is necessary to observe more research variables to determine the phenomena that occur due to turbulent flow.
2. Further research is needed to vary the bed channel material to obtain the value of shear stress for each of these materials.
3. It is necessary to observe the building model variables, which can inhibit turbulent flow and shear stress to reduce the bed channel's excessive scour.
4. Turbulent flow and shear stress become complex study materials so that it is required a variable variation of various parameters that can affect it.

REFERENCES

[1] Golpira A, Koehler K, All A & Baki A B 2020 An Experimental Study: Effects of Boulder Spacing on Mean and Turbulent Flow Characteristics *World Environmental and Water Resources Congress 2020: Hydraulics, Waterways, and Water Distribution Systems Analysis* (Reston, VA: American Society of Civil Engineers) p 31-42

[2] Bretón F, Baki A B M, Link O, Zhu D Z & Rajaratnam N 2013 Flow in nature-like fishway and its relation to fish behavior *Canadian Journal of Civil Engineering* **40**(6), 567-573

[3] Golpira A, Huang F & Baki A 2020 The Effect of Habitat Structure Boulder Spacing on Near-Bed Shear Stress and Turbulent Events in a Gravel Bed Channel *Water* **12**(5) 1423

[4] Howe D, Blenkinsopp C E, Turner I L, Baldock T E & Puleo J A 2019 Direct measurements of bed shear stress under swash flows on steep laboratory slopes at medium to prototype scales *Journal of Marine Science and Engineering* **7**(10) 358

[5] Park J H, Do Kim Y, Park Y S, Jo J A & Kang K 2016 Direct measurement of bottom shear stress under high-velocity flow conditions *Flow Measurement and Instrumentation* **50** 121-127

[6] Jamieson E C, Rennie C D & Townsend R D 2013 Turbulence and vorticity in a laboratory channel bend at equilibrium clear-water scour with and without stream barbs *Journal of Hydraulic Engineering* **139(**3) 259-268

[7] Tsakiris A G, Papanicolaou A T, Hajimirzaie S M & Buchholz J H 2014 Influence of collective boulder array on the surrounding time-averaged and turbulent flow fields *Journal of Mountain Science* **11**(6) 1420-1428

[8] Monsalve A & Yager E M 2017 Bed surface adjustments to spatially variable flow in low relative submergence regimes *Water Resources Research* **53**(11) 9350-9367

[9] Papanicolaou A N, Kramer C M, Tsakiris A G, Stoesser T, Bomminayuni S & Chen Z 2012 Effects of a fully submerged boulder within a boulder array on the mean and turbulent flow fields: Implications to bedload transport *Acta Geophysica* **60**(6) 1502-1546

[10] Ahmed U, Apsley D, Stallard T, Stansby P & Afgan I 2020 Turbulent length scales and budgets of Reynolds stress-transport for open-channel flows; friction Reynolds numbers (R e τ)= 150, 400 and 1020 *Journal of Hydraulic Research* 1-15

[11] Cao H, Ye C, Yan X F, Liu X N & Wang X K 2020 Experimental investigation of turbulent flows through a boulder array placed on a permeable bed *Water Supply* **20**(4) 1281-1293

[12] Falah A R & Sumiadi M 2020 *Kajian Distribusi Tegangan Geser Di Saluran Menikung 120 Dengan Acoustic Doppler Velocimeter (Adv)* (Malang, Indonesia: Universitas Brawijaya)

[13] Cea L, Puertas J & Pena L 2007 Velocity measurements on highly turbulent free surface flow using ADV *Experiments in fluids* **42**(3) 333-348

[14] Rodi W 2017 Turbulence modeling and simulation in hydraulics: A historical review *Journal of Hydraulic Engineering* **143**(5) 03117001

[15] Ikhsan C, Raharjo A P, Legono D & Kironoto B A 2016 Efek Tegangan Geser Dasar yang Terjadi pada Lapisan Pelindung Terhadap Karakteristik Kemiringan Dasar Saluran *Jurnal Teknik Sipil* **23**(3) 197-202

[16] Baki A B M, Zhang W, Zhu D Z & Rajaratnam N 2017 Flow structures in the vicinity of a submerged boulder within a boulder array *Journal of Hydraulic Engineering* **143**(5) 04016104

[17] Mansida A, Hatta M P, Pallu M S & Salintung M 2020 Experimental study the effect of turbulent flows in bend channels as to a result of vegetation groin structure on permeable type *IOP Conference Series: Earth and Environmental Science* (Vol. 419) (Bali, Indonesia: IOP Publishing) p 012121

[18] Latif A A, Pallu M S, Maricar F & Hatta M P 2020 An experimental study of clay soils for preliminary data for scour model in open channels *IOP Conference Series: Earth and Environmental Science* (Vol. 419) (Bali, Indonesia: IOP Publishing) p 012112

[19] Hatta M P, Puspita A I D, Thaha M A, Karamma R, Pongmanda S, Mustari A S & Ibrahim M 2020 Experimental Study of Wave Reflection in Breakwater Overtopping Catcher Model *IOP*

Conference Series: Materials Science and Engineering (Vol. 875) (Bali, Indonesia: IOP p 012026)
[20] Latif A A, Pallu M S, Maricar F & Hatta M P 2019 Pengaruh Tinggi Bukaan Pintu Air terhadap Bilangan Froude dengan Dasar Tanah Lempung pada Saluran Terbuka *Seminar Nasional Teknik Sipil IX 2019* (Vol. 9) (Indonesia: UMS)
[21] Rahim I, Pallu M S, Thaha M A & Maricar F 2017 Sediment Distribution Model for Reservoir Life Service Management *International Journal of Applied Engineering Research* **12**(24) 15398-15405
[22] Latif A, Pallu M S, Maricar F A R O U K & Hatta M P 2020 Study of the Scour Model Around the Sluice Gate of Open Channel *International Journal of Advanced Research in Engineering and Technology* **11**(6)
[23] Kironoto B A 2007 Pengaruh Angkutan Sedimen Dasar (Bed Load) Terhadap Distribusi Kecepatan Gesek Arah Transversal pada Aliran Seragam Saluran Terbuka *Civil Engineering Forum Teknik Sipil* **17**(2) 566-579