INVESTIGATION OF LOCAL SCOURING AND SEDIMENT PATTERNS AROUND THE SOLID AND HOLLOW PILLAR

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ABSTRACT

The existence of a bridge pillar on a river body can cause changes in flow characteristics such as flow patterns to change into the spiral flow or greater turbulence, changes in water flow velocity cause changes in all hydraulic systems so that the change in depth of local scours around the pillars on a bridge. Local scouring occurs due to flow velocity greater than the critical velocity of the sediment. The shape of the pillar is very influential on the depth of scouring, scouring occurs when changes in flow conditions are caused by an increase in the basic shear stress. The purpose of this study is to determine the effect of pillar shape on the scour depth, sediment scours pattern, and the most shallow scoured pillar shape. The tool used is a flume with a length of 15 m, width 1 m and height of water adjusted to the needs. The research method is by testing the depth of scouring on pillars in the form of round and triangular nose pillars, and hollow and triangular round nose pillars, velocity used are fixed, with different water heights so that different Froude and Reynolds numbers are obtained, the velocity is designed based on the principle that local scouring occurs continuously and the sediment transport process does not occur, the basic sediment material used passes filter number no. 10 (2 mm) and retained no. 20 (0.85 mm). Ofthe six types of pillars used the most shallow scour is a hollow pillar with a hollow nose tilted inward the scouring value obtain of $K_1 = 0.6$, in general, that hollow pillars are scoured smaller than intact pillars, while the sedimentary pattern formed around the pillars is for nasal scours triangular pillars are more centred around pillars, while pillars are with a more spread round nose.

Keywords: local scour, hollow pillar, pillar nose shape, sedimentary pattern.

1. INTRODUCTION

Settlements are generally around the river so that in the activity required a crossing bridge as a means of connecting, the bridge is built on a very wide river if the bridge is made more than one span certainly requires a pillar in the middle of the river, so that with the pillars then the pattern of water flow, especially around the pillar becomes changed.

The bridge pillar is a substructure the bridge that functions to support the bridge and is placed in the river flow, the shape and position of the existing pillars in the river flow can affect the river flow.

The pillar is a substructure component that has a function to channel the superstructure load which is then forwarded to the subgrade, for this we need a strong and rigid pillar construction as a support in the middle of the river. The development of the model and shape of the pillar is inseparable from the main function of the pillar in channelling superstructure loads (Medriosa *et all*, 2015, Lutjito, 2015).

Changes in flow due to these pillars can disrupt the stability of the pillars, causing increased scouring around the pillars. If the stability of the pillar is disturbed, then the distribution of the load received by the bridge is also disrupted, with the disruption to the stability of the pillar can cause the bridge to collapse.

Local scouring occurs or shifts in sediment caused by changes in flow velocity due to bridge pillars. The shape of the bridge pillar is very influential on changes in speed that occur around the bridge pillar. The difference in speed that occurs will cause differences in local scouring patterns around the pillar.

Many cases of bridge-building collapse are not only caused by substructure construction factors but the scouring problem around abutments and bridge pillars, this is shown because of the continuous scouring resulting in a decrease in the bridge base of the bridge. With the collapse of the bridge resulting in congestion of economic movements especially those using land transportation, this underlies the importance of scouring research on pillars Yasser*et al.*, 2015, Topczewski *et al.*, 2016.

The purpose of this study is to determine the effect of pillar shape to the scour depth, and changes in basic sedimentary patterns, as well as the most efficient pillar shape. The expected result of pillar variations is that it can be known the minimum scouring potential so that the lowest scouring of pillars can be identified. The shape of the pillars used includes the shape of a triangular nose and circle nose, and round nose pillars and hollow triangles that tilt outward and inward.

Scour and sediment transportation is a natural phenomenon that exists and occurs in river flow, as part of river morphology. Some of the causes of scouring are due to turns, narrowing of flow, and can also be caused by man-made structures that block the flow, such as cribs, pillars, bridge abutments and so on (HEC-20, 1991). Local scouring around buildings occurs due to local flow patterns around river buildings, scouring localized in the river channel occurs due to narrowing of the river, the flow becomes more centralized (Legono, 1990). Geometric measurements are very important to compare before and after other influences on water flow (Fong-Zuo, 2018).

The phenomenon of scour can cause erosion and degradation around the bridge pillars, this degradation takes place continuously until the achievement of supply with sediment transports results in a balance (Ishak, 2018). The existence of a bridge pillar can also occur an imbalance between the amount of sediment transport that is greater than the supply of sediment continuously, this can cause deeper scour holes in the bridge pillar so that it can damage the substructure of the bridge (Lutjito, 2015).

2. METHODOLOGY

2.1. Primary channel

The size of the primary channel used is 1 meter wide and 15 meters long (Figure 1), 2 water pumps with a capacity of 600 litres/minute, circulation pipes, storage tanks with a capacity of 40 m^3, top storage tanks equipped with overflow, floodgates to regulate discharge, and Triangular Notch to measure discharge.

Figure-1. Primary Channel.

2.1.1 Triangular notch

To measure the discharge used Triangular Notch with the formula

$$Q = \frac{8}{15} C_d \sqrt{2g}\ tg(\frac{\theta}{2})\ h^{5/2} \tag{1}$$

Where: Q = discharge (m^3/sec), C_d = coefficient of discharge, g = gravitational force (m^2/sec), θ = angle at the flow triangular notch, h = height of water at the triangular notch (m)

The discharge measurements using the triangular Notch (Figure-2) are measuring velocity with a current-meter tool while measuring sediment topography with the point-gauge tool.

Figure-2. Photo of a triangular notch used to determine the discharge.

To determine the amount of discharge through the triangular notch, the measurement is done starting from the smallest discharge to discharge larger, intended to determine the relationship between the high-water with discharge through the triangular notch.

The results of the measurement of discharge that passes through the triangular notch, produce an equation of the relationship between the amount of discharge that passes through the triangular notch with the height of the water, obtained equation Q = 0.0209 $h^{5/2}$, R = 0.995, as in Table-1 and Figure-3.

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Table-1. The results of the measurementof the relationship between water height and discharge at the triangular Notch.

Height of Water h (cm)	Length of Measurement (seconds)					$h^{5/2}$	Discharge litres/seconds
	t_1	t_2	t_3	t_4	$T_{average}$		
0					0	0	0.00
1.0	594.45	590.43	587.68	580.02	588.15	1.00	0.04
1.5	247.64	255.32	249.33	247.44	249.93	2.76	0.10
2.0	151.20	164.48	156.82	149.32	155.46	5.66	0.16
2.2	113.12	114.51	113.45	113.94	113.76	7.18	0.21
3.0	53.83	53.96	54.24	55.06	54.27	15.59	0.45
3.5	49.03	48.05	48.64	48.22	48.49	22.92	0.50
4.0	32.76	32.29	31.76	31.62	32.11	32.00	0.75
4.2	29.85	29.30	28.80	29.32	29.32	36.15	0.83
4.8	24.19	24.55	24.55	24.44	24.43	50.48	0.99
5.0	19.27	19.53	19.15	19.42	19.34	55.90	1.25
5.5	15.40	15.26	15.07	15.18	15.23	70.94	1.59
6.0	13.99	14.14	13.96	14.04	14.03	88.18	1.72
7.0	9.14	9.50	9.42	9.77	9.46	129.64	2.56
8.0	6.75	6.38	6.78	6.56	6.62	181.02	3.66
9.0	4.66	4.31	4.65	4.59	4.55	243.00	5.32

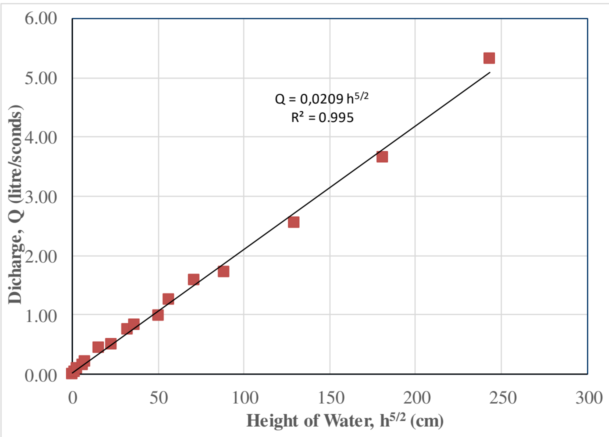

Figure-3. Re.lationship between water height and discharge passing through the triangular notch.

2.1.2 Pillar model

Determination of the thickness of the pillar is based on the width of the channel used, which is 1 m wide and 15 m long. Recommended by Masjedi *et al.*, 2009 the pillar thickness requirement is no more than 10% of the width of the channel, if this does not meet the scouring that occurs due to the narrowing effect so that the pillar thickness used is 10 cm and 50 cm long, Figure-4 shows six kinds of shapes the pillar used.

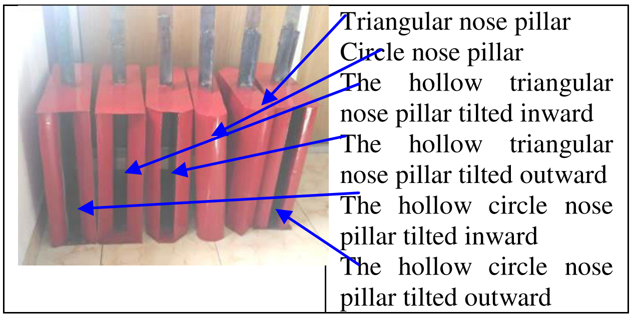

Figure-4. Variation in shape of pillars.

2.2 Circulation of research

Before the research is conducted first, the type of flow chosen will be used. Flow grouping by Chow, 1989 is based on the number Froude $F_r = u/(gR)^{1/2}$ and the Reynolds number $R_e = uR/v$, subcritical flow for $Fr < 1$, critical flow $F_r = 1$, and supercritical flow $F_r > 1$, for Reynolds numbers grouped laminar flow $R_e < 2000$, turbulent flow $R_e > 12500$, transition flow $2000 < R_e < 12500$, where u = flow velocity, g = force of gravity, and R = hydraulic radius (A/P), A = cross-sectional area, P = wetted parameter, v = kinematic viscosity, the flow boundary requirements used in this study are subcritical-turbulent flow.

The critical velocity of the sediment is very important in terms of scouring. The critical velocity of sediments with various theories and formulas, various kinds of sediment diameters that are often used by

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researchers are d_{35}, d_{40}, d_{50}, d_{65}, d_{70}, d_{90}, d_{95}, d_{max}(Xiaoqing, 2003, Stelczer,1981, and Rozovskii, 1963).

For example the critical velocity by Stelczer, 1981

$$u_c = 1.65\left(d_{80}\right)^{0.36} h^{0.14} \tag{2}$$

Where: u_c = critical velocity of sediment (m/sec), d_{80} = sediment diameter (m), h = water flow height (m).

The critical velocity of the sediment can also be determined using the Shields graph (van Rijn, 1990). Local scouring occurs if the shear stress that occurs is greater than the critical shear stress. Three type es the grouping of scouring around pillars, by Wiyono *et al.*, 2006 states that local scouring does not occur and sediment transport processes do not occur, sediment displacement continuously, local scouring occurs continuously and sediment transport processes do not occur, to determine the hydraulic conditions used equation 3. this formula has also been used (Ishak, 2015, Ishak, 2016, and Penny, 2017).

$$0.5 \le u / u_c \le 1 \tag{3}$$

Where: u = average velocity, u_c = critical velocity

On that basis, the critical velocity of the sediment needs to be known in advance, by using equation 2 sediment diameters used pass filter number no. 10 (2 mm) and retained no. 20 (0.85 mm).

Equation of scouring height toward the factors that influence it according to CSU University of Colorado in the FHWA Equation HEC-18

$$\frac{Y_S}{Y_1} = 2K_1K_2K_3\left[\frac{a}{y_1}\right]^{0.63} F_r^{\ 0.43} \tag{4}$$

Where: L = Pillar length (m), a = Pillar width (m), Fr = Froude number directly upstream of the pillar = $V/(gy)^{0.5}$, V = Average velocity (m/s), g = Acceleration of gravity (m/s^2), K_1 = Correction of pillar nose shape, K_2 at equation 5, K_3= Correction factor for bed condition.

$$K_2 = \left(\cos\theta + \frac{L}{a}\sin\theta\right)^{0.65} \tag{5}$$

IfL/a>12 useL/a= 12 as a maximum.

Following are some of the K_1 correction factor values as stated in *WisDOT Bridge Manual* Chapter 13, 2017, Roadney, 1992, and Department of Transport and Main Roads of Queensland State. 2013.can be seen in Table-2.

Table-2. Value of the correction factors for the shape of pillar nose.

Shapes of pillar	Value of K_1	
	Froehlich Equation	**Colorado State University equation**
Square nose	1.3	1.1
Circle nose	1.0	1.0
Circle cylinder	-	1.0
Cylinder group	-	1.0
Triangular nose	0.7	0.9

The research was carried out by spreading sediment along the channel, to regulate the velocity of the water a sluice was installed downstream of the channel, installing a pillar model in the middle of the canal, a circulation pump that functions to drain the water, the test was stopped if the sediment topography did not change again. Expressed by Wiyono *et al*, 2006 that for condition local scour to occur continuously and the process of sediment transportation did not occur, it was found that after 2 hours the sediment topography had not changed.

Water is pumped from the main reservoir to the second reservoir as high as 2.75 meters. Overflow from the second reservoir is channelled back to the main reservoir to allow the flow of discharge in the fixed channel. As water flows into the channel, the water level is controlled by the downstream gate, which is connected back to the main reservoir, as shown in Figure-5 this picture shows the following:

a) Main reservoir with a capacity of 40 m^3
b) Suction pipe 2x Ø2 "from the reservoir to the water pump
c) Water pump capacity 2 x 600 litre/minute
d) Push pipe 2x Ø2 "from the pump to the top reservoir
e) Water tower high of 3 m
f) Top reservoir
g) Stop valve to regulate water from the top reservoir to the primary channel
h) Overflow channel which serves to stabilize the discharge
i) The triangular notch that functions to know the discharge that flows in the primary channel
j) Filter that serves to reduce water turbulence
k) Arrangement of the point gauge and the place of the pillar
l) The door on the downstream channel that serves to regulate the water level
m) Downstream reservoirs that function as water to flow into pipes
n) Pipe 2 Ø2" the function of connecting the primary channel with a reservoir

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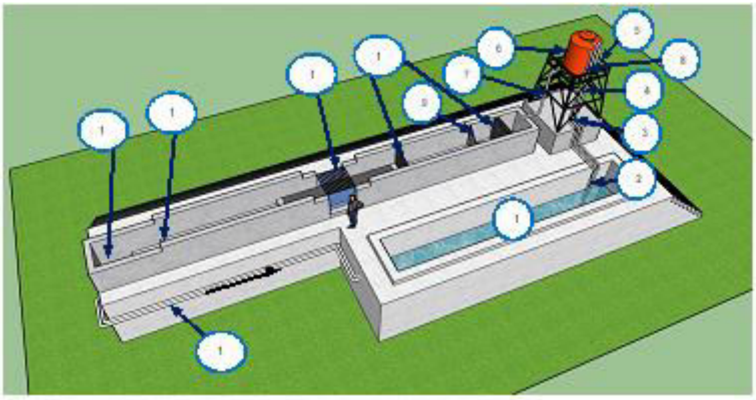

Figure-5. Circulation of research.

3. RESULTS AND DISCUSSIONS

3.1 Pillar of triangular nose

Measuring the height of the sediment with a point gauge tool, and the depth of scouring around the pillars was measured with a water pass device, the water discharge used Q = 10.405 litres/second, the results in Figure-6 show that scouring around the pillar for water height of 5.6 cm with scouring height of 3.7 cm, deeper than the flow height of 7.6 cm with scouring height of 2.6 cm, while the measurement of sedimentary scouring patterns for the triangular nose pillars shows that scouring occurs centred around the pillar.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-6. Photo of sediment scouring for triangular nose pillars.

3.2 Hollow pillar with sharp nose tilted inward and outward

Analysis of Figures 7 and 8 which occurs is greater in the hollow pillars with the nose tilted outward compared to the hollow pillar with the nose tilted inward, while the overall scour is larger for pillars that are not hollow. The scour that occurs on a pillar with the nose tilted inward does not widen and results in a lower scour.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-7. Photo scouring of hollow pillars with a triangular nose tilted inward.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-8. Photo scouring on hollow pillars with a triangular nose and tilted outward.

Of the two types of water flow height of 5.6 cm and 7.6 cm, this shows that the greater the number of Froude produces deeper scours, the same conditions occur in the other pillars.

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3.3. Pillar of circle nose

Figure-10 shows the height of water flow 5.6 cm produces scour of 3.9 cm, deeper than the water flow height of 7.6 cm produces scouring 2.7 cm, while the measurement of scouring pattern using a point gauge tool is known that for a round nose pillar it produces scours that occur wider and deeper than with the triangular nose pillar scouring the results centred around the pillar.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-9. Photo of circle nose pillars.

3.4. Hollow pillar with circle nose tilted inward and outward

Hollow pillars with circle nose slanted inward Figure-10 and measuring scour patterns using a point gauge tool. The results show that the scour is widening, and downstream of the pillar occur of scouring deeper.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-10. Photo scouring on hollow pillars with a circle nose and tilted inward.

a. Scour for water height of 5.6 cm	b. Scour for water height of 7.6 cm

Figure-11. Photo scouring for hollow pillars with a circle nose and tilted outward.

The results show that the greater scouring that occurs on a hollow pillar with a circle nose tilted outward, compared hollow pillar with a circle nose tilted inward as Figures 10 and 11, while the topographic pattern that occurs to the nose pillar tilted outward scours widened compared to the nose tilted inward, while in the part downstream pillar for nose tilted inward incline to occur scours in the middle part.

All experiments using the same discharge of the two types of water flow height of 5.6 cm and 7.6 cm, the results show that the greater the Froude number scour deeper according to the results of the measurement of the six kinds of triangular and circle nose pillars, the hollow pillars tilted inward and outward.

The all of pillar prototype produces the greatest scouring for pillars that are not hollow. The results of sediment topographic measurements show that the effect of scouring extends outward for the hollow pillar with the circle nose tilted outward, and the lowest scour is the hollow pillar of the triangular nose tilted inward.

As data from the Bridge Scour Manual (2013) in Table-1 for the correction value of the pillar nose shape factor shows that for the round nose pillar the value of K_1 = 1.0 while the nose triangle K_1 = 0.9 and 0.7. Based on this value by calculating the interpolation based on the value of the scour depth that occurs in each test, it is found that from the six types of pillars used the smallest scouring is a hollow triangular hollow nose pillar with a K_1 value of 0.6.Continuously, the oblique hollow triangular nose pillar outward value of K_1 = 0.62, the round hollow pillar inward K_1= 0.65, the hollow round nasal pillar oblique exit K_1 = 0.67, so in particular applications the use of bridge pillars in the river to minimize scour the best be used for triangle nose pillars with inward-sloping hollow.

4. CONCLUSIONS

Of the six types of pillars used the smallest scouring is a hollow triangular nose pillar inclined inward with a *K1* value of 0.6, successively, Hollow triangular nose pillars tilted outward, hollow round nose pillars tilted inward, hollow round nose pillars tilted outward, triangular nose pillars and the largest are round nose pillars. so that in particular applications the use of bridge pillars in the river to minimize scouring more efficient used hollow triangle nose pillars tilted inward.

Sediment scour pattern shows that the round nose pillar shows scour occur widening deeper around the pillar compared to the triangular nose pillar scours widening to the side.

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