VOL. 10, NO. 12, JULY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PREDICTION OF SCOURING IN THE BRIDGE PILLAR ON INTERMITTENT RIVER

M. Galib Ishak, Irianto Uno and Saparuddin
Department of Civil Engineering, Faculty of Engineering, Tadulako University, Jalan Sukarno-Hatta, Palu, Central Sulawesi, Indonesia
E-Mail: galibishak@yahoo.co.id

ABSTRACT

In the planning for bridge pillar in the river, things that need to be considered are the stability and strength of pillar. Other things that also should be taken into consideration in planning is scouring that occur after the bridge pillars exist. The objective of research is to predict scouring in the river due to the influence of the pillars. This research was conducted on the intermittent river in the eastern side of Palu Bay in Central Sulawesi, Indonesia. In this area, there are eight rivers but only four rivers have bridge with three spans, include Taipa River, Labuan River, Lambara River and Toaya River, and all these rivers flow toward Palu Bay. The method used in this research is by calculate and directly measure the variables that affect on the scouring height, such as catchment area, river slope, sediment diameter, rainfall, pillar width, average velocity and height of flow. By taking into account the effect of those variables, the results that are achieved in this research are closer to the higher of scouring around pillars from direct measurement in the research locations. This study is also compared with those conducted by previous researchers, with the results show that the closest result is the Carsten and Froehlich equation.

Keywords: pillars, scour, river, intermittent

INTRODUCTION

In the area of eastern side of Palu Bay Central Sulawesi - Indonesia, there are some intermittent rivers such as Poboya River, Kawatuna River, Vatutela River, Bulubiongga River, Taipa River, Labuan River , Lambara River, and Toaya River. These rivers situated closely along less than 45 km in the downstream side, which all flow into the Palu Bay. Among all bridges that across these rivers there are only four rivers that use pillars, while the rest have only one span. During the rain season all the rivers are drained but after a few days without rain the rivers become dry without any flow of water, the condition that the rivers can be defined as intermittent rivers. Some of these rivers are wide enough so that the bridges have to be constructed in three spans on two supporting pillars. In Toaya river, there exist two bridges with three spans, each of them related to its relative position namely Taipa Atas Bridge (upstream) and Taipa Bawah Bridge (downstream).

Scour in pillar

Flow distribution that occur around the pillars bring scouring effect in which this scouring is influenced by the presence of very large shear stress at the front and sides of pillar. High scouring is also affected by the amount of sediments arround pillar, and process of scouring that happen around this pillar called local scouring. Depth of scour strongly influenced by the flow velocity and shear velocity of sediments (u_c) that usually used D_{50} or median diameter. In certain condition balanced scouring is occur which mean out flux sediment is in the same amount with influx sediment in scouring area next to pillar site.

Scour as the result of channel narrowing will not happen if the pillar width is not more than 10% of channel width, as it recommended by Chiew (1987) in Masjedi *et al* (2009). This is to know that hydraulic change that happen as the result of the existence of pillar in the middle of channel is not caused by narrowing of the channel.

Figure-1. Riverbed photo of Taipa river in dry state.

Nina (2007), based on her research on local scouring in the abutment of Labuan Bridge found that the depth of scouring is 1.169 m for 166.31 m^3/sec discharge, and 1.322 m for 189.81 m^3/sec discharge. The results were

ARPN Journal of Engineering and Applied Sciences

calculated by using one of Garde and Raju equation, and other equations as well.

Critical velocity

Critical velocity calculation that occurs in a stream, many researchers have formulated as follows: Jaroki (1963) in Saleh (2012) suggested that if the average velocity greater than the velocity at the base it will result in the initial movement of sediment, with the equation;

$$u_{cr} = 1{,}4\sqrt{gD}\ln\frac{H}{7\,d}.$$

Where: u_{cr} = critical velocity (m/sec); H = average height of water (m); this equation is only valid for the ū /D> 60.

Critical velocity has also been formulated by many researchers in Stelczer (1981), among others: Velikhanov (1931), Mavis (1935), Bogardi-Yen (1938), Gonstharov (1954) and scour depth formula by Jorge (2012). The result of the evaluation of scour equations by Ettema*et al* (2011) recommend that the CSU equation in HEC11-18 be replaced with the Sheppard-Melville equation. This equation is basicly integration process that worked by Sheppard and Miller and by Melville as well (1997). For clear-water scour, the Sheppard-Melville equation is:

$$\frac{y_s}{b} = 2{,}5\, f_1\left(\frac{h}{b}\right) f_2\left(\frac{\bar{u}}{u_c}\right) f_3\left(\frac{b}{D_{50}}\right)$$

Critical velocity u_c is

$$u_c = 11{,}17\, h^{1/6} D_{50}^{1/3}$$

Where

f_1 = flow-structure interaction,
f_2 = flow-sediment interaction,
f_3 = sediment -structure interaction,
y_s (t) = scour depth at time t (ft),
y_s = scour depth (ft),
h = flow height (ft),
b = pillar diameter (ft),
D_{50} = median grain size (ft).

From first motion research by Shields (1936) in Leo C. van Rijn (1989), Shields Graph was tried formulated by Bonnefille (1963) and Yalin (1972) in which in Shields graph has been made a dimensionless number, that is the vertical axis belongs to motion parameter while horizontal is the particle parameters. By using these parameters, the graph can be expressed Shields;

$\Psi_{cr} = 0{,}24\, D_*^{-1}$ for value $1 < D_* \leq 4$
$\Psi_{cr} = 0{,}14\, D_*^{-0{,}64}$ for value $4 < D_* \leq 10$
$\Psi_{cr} = 0{,}04\, D_*^{-0{,}1}$ for value $10 < D_* \leq 20$
$\Psi_{cr} = 0{,}013\, D_*^{-0{,}29}$ for value $20 < D_* \leq 150$
$\Psi_{cr} = 0{,}055$ for value $D_* > 150$

$$D_* = D_{50}\left(\frac{\Delta\, g}{\nu^2}\right)^{1/3}, \text{ and } \quad \Psi cr = \frac{\tau_{*cr}}{(\rho_s - \rho_a)\, g\, D_{50}}$$

Where

Ψcr = critical shields parameter (dimensionless),
D_* = particle parameters (dimensionless),
τ_{cr}= critical shear stress,
ρ_s = mass density of sediment,
ρ_a = mass density of water,
g = gravity acceleration,
D_{50} = diameter of median,
$\Delta = \frac{\rho_s - \rho_a}{\rho_a}$,
ν = Kinematic viscosity,
$u_c = (\tau_c/\rho)^{0.5}$.

Equation of local scouring at Pillar

Some formulas of local scouring in the pillar by Rodney, 1992:

- Laursen Equation (1956) and (1958):

  $D = 1.5B^{0,7}H^{0,3}$, ft, D = scour depth, B = width of the pillar, H = height of flow.

- Chitale Equation (1962);

  $D = H\,(6.65(Fr)-5.49(Fr)^2-0.51)$,ft, where Fr is the Froude number defined as $Fr = (\bar{u}/(gH))^{0,5}$, ū = average velocity (ft/sec), g = gravity acceleration

- Cartens Equation (1966):

  $D = B[0.546[((N_S)^2-1.64)/((N_S)^2-5.02)]^{-0,83}]$, where $N_S = \bar{u}/[(s-l)gD_m]^{0,5}$, s= 2,65 specific gravity of sand, D_m = median bed-material diameter.

- Froehlich Equation (1987):

  $D = B[0{,}32\phi\left(\frac{B'}{B}\right)^{0{,}62}\left(\frac{H}{B}\right)^{0{,}46} Fr^{0{,}2}\left(\frac{B}{D_m}\right)^{0{,}46}$ where: ϕ = pillar shape correction factor, B = pillar width projected normal to flow, B' = B cosα+L sinα, α = flow angle, degrees, α = 0 parallel to flow, L = length of pillar in ft.

- Equation of Colorado State University (CSU) (1990):

ARPN Journal of Engineering and Applied Sciences

- $D = H [2K_1\ K_2\ (B/H)^{0,5}\ (Fr)^{0,43}]$ where; K_1 = pillar shape correction factor, K_2 = angle correction factor.

RESEARCH PURPOSES

This research is to determine the relationship between depth of scour with the affecting variables such as catchment area, river slope, sediment diameter, pillar width, river width, rainfall intensity, and the average of flow velocity, by making a formulation of relationship among eight variables that are interconnected. From these variables, it will be made graphs on all researched rivers, in which the results can be used to predict the depth of scour around bridge pillar to be built.

METHODOLOGY OF RESEARCH

This research was conducted with supporting data from relevant agencies and direct field measurement on intermittent rivers that situated in the eastward of Palu Bay. The research data that will be acquired for doing the objective calculation are as follow:

a) Measurement of the river elevation, measured at least 500 m both upstream and downstream, to get the slope of the river in a longitudinal direction.
b) Measure and draw river cross sections in order to get depth of scour close to pillar. Width and length of pillar also measured in this part.
c) Measure catchment area of each river by using topographical map data.
d) Determine design rainfall for 50 years return period..
e) Calculate the flood discharge for 50 years return period
f) Data of sediment is taken from cross sectional part, include direct grain size measurement and sieve analysis as well in order to determine the value of sediment median.
g) Calculate the average velocity in focus points based on the variables that have been calculated by trial and error way.

RESULTS AND DISCUSSIONS

Of all the rivers mentioned above there are only four rivers with bridge three spans while the rest only one span. These rivers are Taipa river, Lambara river, Toaya river, and the Labuan river, and among these rivers there is one that has bridges with 3 spans.

Calculation to obtain 50-years flood discharge designs as a basis to determine the water level, flow cross-sectional area and debit is done from rainfall data and then design rainfall for 50-years return period is calculated. Before that, the catchment area is calculated by using secondary data. The discharge result can be used to analyze flow velocity around planned bridge.

From the use of critical velocity equation on a river to determine the maximum velocity that have been occurred with the use of sediment diameter, or also with the use Shields graph it can be determined maximum velocity that has been occurred on a river cross section. This is intend to explain that the past maximum velocity has caused sediment movement toward where the material will be the object of research. Sediment size is determined with sieve tool for smaller size while field measurement for the larger one. The size most often used in sediment research is median diameter $D_{50,}$ some researcher also used D_{60}, D_{80}, and D_{90}, and in this research use D_{50}. This research use another method to find average velocity of river flow with the use of discharge of 50 years return period.

The step of research are as follows:

a) Take field measurements for the local slope of the river, topography around the bridge, terrain slope around the bridge, while other data such as the catchment area and general slope of the total river length is measured from the topography contour map, with the results as shown in Table-1 below:

Table-1. Catchment areas and river slopes.

Name of river	Catchment area (km^2)	Calculated general slope of river (I)				River local slope (S)			
		Elevation (m)		River length (km)	I	Elevation		Measured river length (m)	S
		Upstream	Downstream			Upstream ± 500 m	Downstream ± 500 m		
Toaya River	69.38	1,608.00	17.94	22.745	0.06991	26.167	9.711	1000	0.01646
Labuan River	126.11	1,430.00	16.65	24.317	0.05813	24.269	8.830	1000	0.01544
Lambara River	19.77	1,125.00	49.84	17.885	0.06011	56.656	43.030	1000	0.01363
Taipa Atas River	82.62	938.33	124.57	17.232	0.04723	139.408	111.793	1000	0.02761
Taipa Bawah River	88.83	938.33	36.13	20.877	0.04322	48.216	24.535	1000	0.02368

Note: All these rivers as it measured in the field have three-span bridge

ARPN Journal of Engineering and Applied Sciences

b) Intermittent rivers that have been researched have characteristic of un continue flow, and there is no Automatic Water Level Record (AWLR) installed. This is the reason discharge calculation is made with the assumption that Q = f (i, A, α, T, β, RT), where A = catchment area, i = slope of the river at the control points (height difference divided by horizontal distance between upstream and downstream), α = coefficient of flow, T = flood arrival time, β = coefficient of reduction, and RT = rainfall design that will be used to calculate the discharge for the period of 50-years return period. The procedures are use follow :

- Determine the maximum daily rainfall
- Check the data abnormality
- Calculate the design rainfall
- Test the validity of the data
- Calculate the design flood discharge with the methods used depending on the catchment area.

The results of calculation of each river discharge are as follow: Toaya River 168.689 m^3/s, Labuan River 190.49 m^3/s, Lambara River 96.477 m3/s. Upper Taipa River 156.89 m^3/and Lower Taipa River is169.211 m^3/s.

c) Calculation of average velocity on control points in the cross section below bridge is made with the assumption that ū = f (n, Q, A, P, R, S), where n = Manning roughness coefficient, Q = discharge for 50 years return period (m^3/s), A = cross-sectional area (m^2), P = wet perimeter (m), R = A/P = hydraulic radius (m), S = longitudinal/local slope of river base around control points that obtained from topographic survey along 500 m up and down stream. By using trial and error method, the height of water and other dimensions can be calculated until finding the same discharge or close to design discharge value. The last velocity average value is the value that will be used. Figure-3 is topography contour map of one of the rivers being researched, whereas Figure-4 and Figure-5 are cross sections under the bridge of the two of five rivers

d) Manning roughness is calculated as proposed by Cowan (1956) in Chow (1989) that the value of n results in the turbulent, and from some of the major factors that influence the roughness coefficient according to Cowan value of n can be calculated by the formula:

$$n = (n_o + n_1 + n_2 + n_3 + n_4)\, m_5.$$

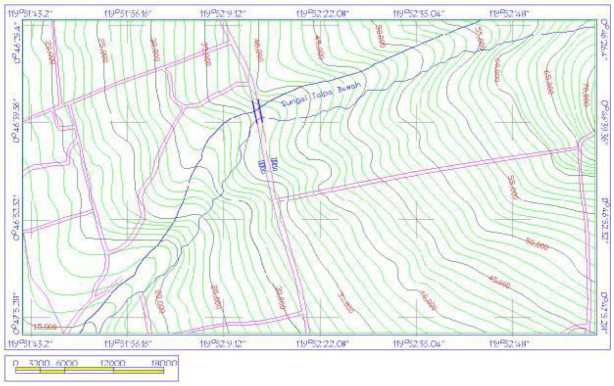

Figure-2. Topography around bridge of Taipa river.

Figure-3. Photos of Taipa bridge from downstream to upstream.

Where

n_o = forming material value,
n_1 = degree of irregularity,
n_2 = variation of the channel cross section,
n_3 = relative effects of obstructions,
n_4 = value for vegetation and flow conditions,
m_5 = correction factor for meandering.

After reviewed and calculated the variable n for each stream the results are tabulated as shown in Table-2. For water level and mean flow velocity that occur in each river in focus points, when after trial and error method result in the discharge close or the same, the final value of water level and velocity are used as calculation base.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

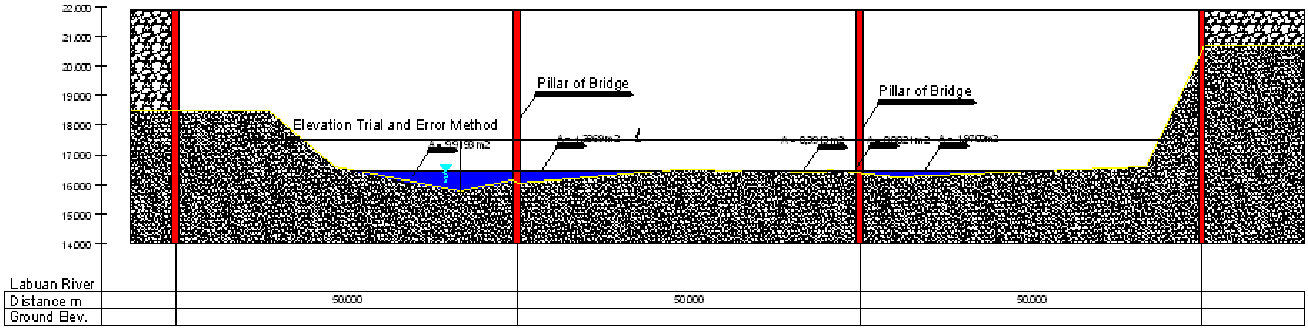

Figure-4. Cross section profile underneath the bridge of Labuan River.

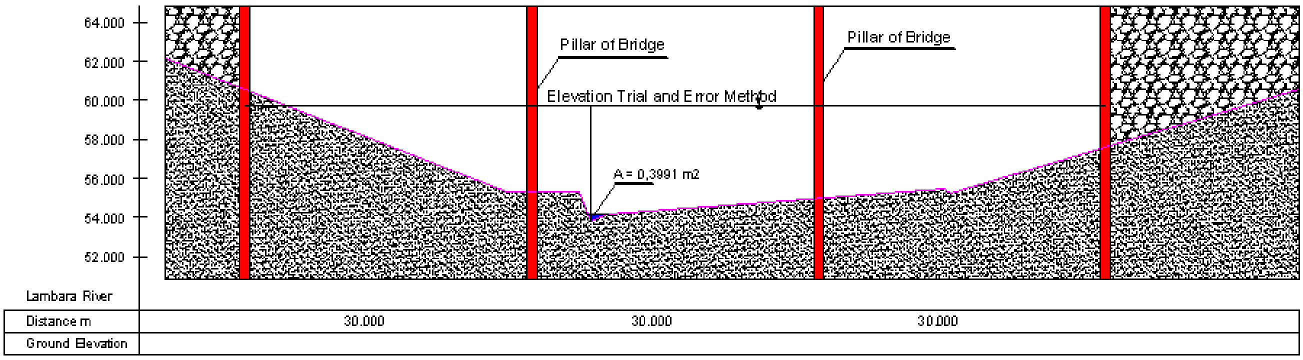

Figure-5. Cross section profile underneath the bridge of Lambara River.

Table-2. Calculations dimensional of river hydraulic.

No.	Name of river	Bed Roughness	Discharge	Water Height	Cross-sectional area	Wet Perimeter	Hydraulic radius	River slope	Water average velocity
		n	Q	h	A	P	R=A/P	S	$\bar{u}=1/n^* R^{2/3}*S^{1/2}$
		-	m^3/sec	m	m^2	m	m	-	m/sec
1	Toaya River	0.037	168.59	2.05	48.20	47.30	1.019	0.01646	3.516
2	Labuan River	0.040	190.50	1.17	78.96	123.64	0.639	0.01544	2.301
3	Lambara River	0.035	96.477	1.22	50.70	104.14	0.487	0.01363	2.064
4	Taipa Atas River	0.036	156.89	2.03	53,00	82.40	0.643	0.02761	3.440
5	Taipa Bawah River	0.030	169.21	0.95	50.95	67.30	0.757	0.02368	3.455

e) Formulate scour depth (h_d) with assuming that $h_d = f(\bar{u}, B, b, D_s, g, R_T, \rho, \rho_s)$ where; $\bar{u}$ = average water flow velocity under the bridge (m/sec), B = river width under the bridge (m), b = pillar width (m), D_s = median diameter (m), g = gravity force (m/sec^2), R_T = design rainfall (m), ρ = water density (kg/m^3), ρ_s = sediment density (kg/m^3). From the above variables, non dimensional number is calculated and designed in order to find regression value from scour depth graph. Dimensionless number graph is made in two axes, one is y-axis refers to the scour depth and another is x-axis represents the variable that affect scour depth. Constant variables are g = 9.81 m/s^2, ρ = 1000 kg/m^3, ρ_s = 2650 kg/m^3, the rainfall intensity = 207.587 mm (data from Mutiara Rainfall Station in Palu) while inconstant variables in each of catchment area include river width in

ARPN Journal of Engineering and Applied Sciences

the reviewed spot (bridge site), pillar width and sediment diameter. From calculation results of five rivers as shown in Table-2 below, the regression equation has been obtained as follow:

$$y = 0.985*10^{-12}x^3-3.026*10^{-8}x^2+3.234*10^{-4}x+2.268$$

Tabel-2. Calculation of affect variables and scour depths.

No.	Name of river	River effective width	Pillar width	Sediment diameter	Rainfall intensity	Water average velocity	Scour depth	$\bar{u}\ B\left(\frac{b\ D_s}{R_T\sqrt{gR_T{}^3}}\right)\left(\frac{\rho_s}{\rho}\right)$	$\frac{h_d}{R_T}$
		B	b	D_s	R_T	ū	h_d	Axis-X	Axis-Y
		m	m	m	m	m/sec	m	-	-
1	River of Toaya	120	2.5	0.080	0.207587	3.516	0.8	17515.38	3.85
2	River of Labuan	128	2.5	0.008	0.207587	2.301	0.6	1222,69	2.89
3	River of Lambara	109	2.0	0.060	0.207587	2.064	0.9	5604.21	4.34
4	River of Taipa Atas	90	3.0	0.120	0.207587	3.440	1.2	23134.07	5.78
5	River of Taipa Bawah	79	3.0	0.025	0.207587	3.455	0.4	4249.28	1.93

More detail of the above regression equation is presented below.

$$\frac{h_d}{R_T} = (0.985 * 10^{-12})\left[\bar{u}B\left(\frac{b\ D_s}{R_T{}^3\sqrt{gR_T}}\right)\left(\frac{\rho_s}{\rho}\right)\right]^3 - (3.026 * 10^{-08})\left[\bar{u}B\left(\frac{b\ D_s}{R_T{}^3\sqrt{gR_T}}\right)\left(\frac{\rho_s}{\rho}\right)\right]^2 + 3.234 * 10^{-04} * \bar{u}B\left(\frac{b\ D_s}{R_T{}^3\sqrt{gR_T}}\right)\left(\frac{\rho_s}{\rho}\right) + 2.268$$

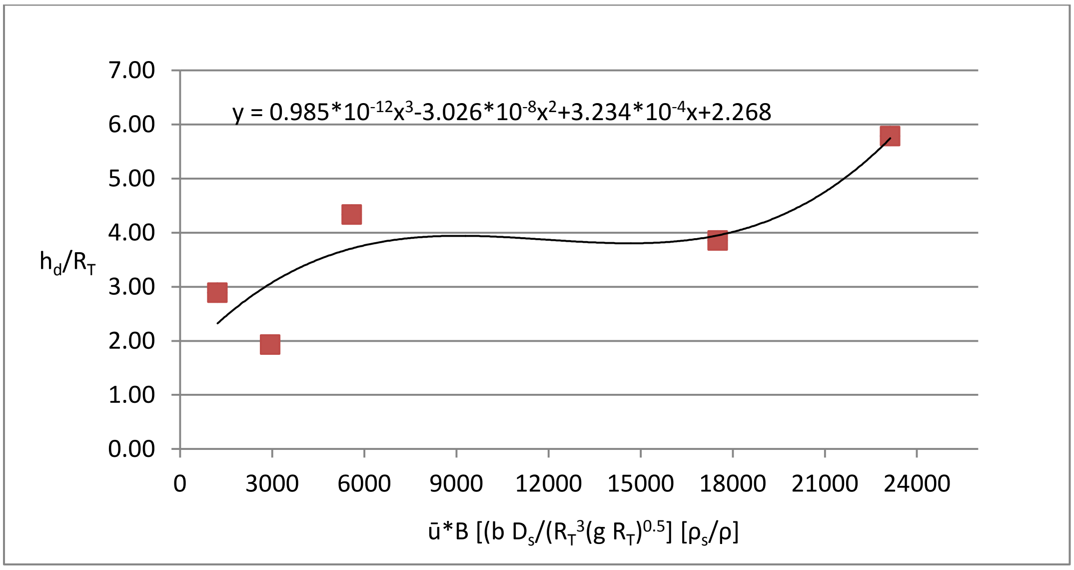

Figure-6. Graph of the relationship between variables and influence of scour depth at bridge pillars.

f) Comparing this research results on scour depth as shown in Table-2 with the calculations using Laursen, Chitale, Castens, Froehlich, and Colorado State University (CSU) equations, all these previous formulas is in the British Unit. Therefore, the values to be calculated in this research have to be done with British Unit. After that, all

ARPN Journal of Engineering and Applied Sciences

the results must beconvert again into Universal or International Unit. In the Laursen method, scour depth at pillar is based on the flow height without considering velocity variable and sediment diameter. Chitale, for this scour depth only use water height and velocity variables, CSU includes flow height, pillar width and flow velocity but without considering sediment diameter. While in Carstens and Froehlich equation beside take into account the flow height, pillar width also use flow velocity and sediment diameter. Among those five equations the closer one is Carstens an Froehlich equation because more variables involved. Table-3 below shows the comparison of all calculation results among those previous methods with this research.

Table-3. Comparison of the results among this research with the previous equations.

No.	Name of river	Scours of high	Results of calculation with equation					Regression equations
			Laursen	Chitale	Carstens	Froehlich	CSU	
		m	m	m	m	m	m	m
1	River of Toaya	0.800	3.533	2.726	1.185	0.916	4.201	0.819
2	River of Labuan	0.600	2.986	1.725	0.803	0.827	3.245	0.544
3	River of Lambara	0.900	3.022	2.844	-	0.734	2.890	0.686
4	River of Taipa Atas	1.200	4.014	2.790	2.923	0.988	4.685	1.194
5	River of Taipa Bawah	0.400	3.294	0.333	0.996	0.885	4.294	0.658

g) This research generate equation $y = 0.985*10^{-12}x^3-3.026*10^{-08}x^2+3.234*10^{-04}x+2.268$. The equation can be used to predict scour depth that will occur in intermittent river in case the bridge is designed on the support of pillar columns. When a bridge will be built pillars, planners determine the width of the pillar, then other variables such as river slope, flow velocity calculated from discharge of 50 years return period, median sediment diameter D_{50}, rainfall intensity of 50 years return period, and the substituted into the equation $\bar{u}B\ [(b\ D_s/(R_T^3\ (g\ R_T)^{0.5}]\ [\rho_s/\rho]$. The obtained results are plotted on the x-axis, so that the h_d/R_T values can be obtained as well.

CONCLUSION AND RECOMMENDATIONS

From four catchment areas where these five rivers located it can be drawn conclusion as follows:

a) Compared with the results of previous studies, it is shown that calculation with Carstens and Froehlich equation that includes flow height, pillar width, flow velocity and sediment diameter give value that close to the direct measuring of scour depth in the field.
b) This research result can be used to predict scour depth around pillar site by using a regression formula $y = 0.985*10^{-12}x^3-3.026*10^{-08}x^2+3.234*10^{-04}x+2.268$, where value $x = \bar{u}B\ [(b\ D_s/(R_T^3(g\ R_T)^{0.5}]\ [\rho_s/\rho]$ and value $y = h_d/R_T$
c) This research is most ideal when more intermittent rivers are included as samples, and include intermittent rivers that located in more distance as well. The input data to obtain different equation is rainfall, which means that rainfall intensity no longer become constant variable..
d) The novelty of this research is by taking into account variables to determine scour in the intermittent river from upstream until downstream. Among those variables are total river slope, local river slope, catchment area, riverbed roughness and rainfall design. From those variables also can be calculated the amount of flow discharge. Flow discharge is used to calculate hydraulic dimension, flow height, river width and flow velocity. All those data is then used to find scour depth after sediment diameter is measured and pillar width is determined.

ACKNOWLEDGEMENTS

We, the authors would like to thank to Prof. Dr Ir. Muhammad Basir Cyio, MS as Rector of the University of Tadulako who has created a good enough academic atmosphere on campus, so that writing can be realized.

REFERENCES

Chow Ven Te. 1989. Open Channel Hydraulics, Publications of Erlangga Bandung.

Jorge E., Pagan-Ortiz. 2012, Pillar Scour Clear-Water Conditions with Non-Uniform Bed Materials, Publications No. FHWA-HRT-12-022, Georgetown.

Leo C. van Rijn. 1984. Sediment transport. Part I : Bed Load Trasport. Journal Of Hydraulic Engineering, Vol.

ARPN Journal of Engineering and Applied Sciences

110. No. 10. ISSN 0733-9429/84/0010-1431/$01.00. Paper No. 19220.

Masjedi A., Kazemi H. and Foroushani E. P. 2009. Experimental Studi on the Effect of Cylindrical Bridge Pillar Position on the Scoring Depth in the River Bend, 33rd IAHR Congress: Water Engineering for a Sustainable Environmental Copyright °C 2009 by International Association of Hydraulic Engineering and Research (IAHR) ISBN: 978-94-90365-01-1.

Nina Bariroh Rustiati. 2007. Local scour Around Abutment of Bridge Labuan, Jurnal SMARTek. 5(3): 157-165.

http://download.portalgaruda.org/article.php?article=10668&val=750.

Rodney E. Southard. 1992. Scour Around Bridge Pillars on Streams in Arkansas, U.S. Geological Survey Water-Resources Investigations Report 92-4126.

Saleh Pallu M. 2012. The Theory of Sediment Transport in Open Channels, Publications Telaga Zam Zam, ISBN 978-979-3437-49-1, Makassar.

Stelezer K. 1981. Bed Load Transport (Theory and Practice), Water Resources Publications, Littleton, Colorado 80161 U.S.A.