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THE EFFECT OF THICKNESS OF PILLAR IN THE CHANNEL BEND TO CHANGES THE COEFFICIENT OF SUPERELEVATION

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Abstract

The present study discusses phenomena occurred in a natural channel where a bridge is built in a river bend. The present study aims at determining the effect of pillars thickness on water surface slope in transverse direction on channel bend which is defined in superelevation coefficient (C_s). Physical modelling applies 180^o channel bend, 0.75 m radius, and 0.5 m width. It was applied in both with pillar and without pillar flows in subcritical-turbulent flow. For the flows with pillar there were pillar interval of 30^o and 60^o. The results show that the highest value of C_s (7.826) is found in the flows with pillar of the 30^o interval in 30^o river bend. In the interval of 60^o where the pillar thickness is 3 cm, the C_s value is greater than when the pillar thickness is 2 cm, on the other hand in the interval of 30^o the C_s value is smaller. It is recommended for the next research to apply hydraulic condition with average velocity divided by the critical velocity must be greater than one.

Keywords: Bend, River, Effect, Thickness of pillar, Superelevation.

1. Introduction

River on the upstream side is generally located on the steep slopes of the mountain and flow properties are critical-turbulent, and further down the slope more gentle velocity of the water flow become decreased and sediment began to settle causing obstacles to the flow of water as a result the direction of the river flow turned into meander and the river body more wide and the flow turned into subcritical-turbulent. At the bend of the river occur the centrifugal force influencing the rise in water level on the outside of the bend and decrease in water level on the inside of the bend. Those events is defined as the superelevation [1 -3].

Nomenclatures

A	Cross-sectional area, m^2
B	Channel width, m
C_r	Water surface slope coefficients
C_s	Coefficient of superelevation
D	Diameter sediment, m
F_r	Froude number
g	Force of gravity, m/s^2
h	High water flow, m
H_s	Height difference of each segment, m
P	Wetted perimeter, m
R	Hydraulic radius (A/P), m
r	Radial coordinate, m
r_c	Channel bend radius, m
R_e	Reynolds number
S_r	Transverse slope of the channel at the bend
u	Average water velocity, m/s
u_c	Critical flow velocity, m/s
u_m	Average velocity channel segment, m/s

Greek Symbol

ν	Kinematic viscosity, m^2/s

Specific characteristics on a bend of the river, is the water flow in bend causes scour on the outside of the bend, while on the inside of the bend occur the precipitates continuously [4,5]. The collision of water on cylindrical pillars that lead to whirl pool, required maximum size of the width of the pillar model is 10% of the total width of the channel to avoid the influence on the channel walls due to the effect of narrowing [5].

Results of the study [4], which is done with the channel bend of 193^o, showed that the changes in topography for the discharge of 63 litre/s with the maximum scour on outside of the bend line, and on the inside bends of channel occur the silting, shown also the scour at 6 points. The inclination of channel bottom begins at the angle of 31^o while the deepest on the outside of the bend in the angle of 70^o and the scour begin to decline after the bend angle of 90^o. Other studies (6,7) on channel bend show that beside the existence of longitudinal velocity in channel direction there also transversal velocity that perpendicular working below water surface. These processes cause scoring at outside bend, and based on sediment contour it has been found that the maximum scouring occurs around bend angle of 45^o.

Research on the formation of river bend [8] with the use of numerical simulation, one of the results is that the growth of point bars effect the distribution of shear stresses, secondary currents and flow momentum, and the model properly simulates the various modes of deformation of meandering channels, such as downstream and upstream migration, lateral extension and rotation of meander bends. Other research [9] for reproducing the variety of bend forms observed in nature not only on short timescales, typical of the evolution of single meanders before cutoff, but also on the long term, when older reaches are systematically removed from the active river by repeated cutoff events. Natural movement of channel bend continuously, as developed by [10] the model could be used to compare different hydrologic scenarios and alternative land use plans. The model could also be used to evaluate proposed highway and bridge alignments in the vicinity of the river channel and floodplain.

The present study conducted to obtaining actual phenomena occurred in natural channel where a bridge pillar is built in a river bend. The present study aims at determining the effect of pillars thickness on water surface slope in transverse direction on channel bend which is defined in superelevation coefficient (C_s). Conducted at the Laboratory of Hydraulics Department of Civil Engineering, Faculty of Engineering, University of Tadulako, Palu, Central Sulawesi, Indonesia.

2. Regulatory Equation

2.1. Scour in pillar

Classification of the type of scouring that occurs in rivers [11]: first the general scour is the scouring that occurs through natural processes on the river. The second is the scouring happened due to constriction in the river channel called constriction scour, and the third local scours namely scouring generally caused by the building of water, such as bridge pillars, there are two kinds of local scour, the first is sediment movement occurs only on the pillar called clear water scour and the second sediment transport occurs continuously called live bed scour.

2.1.1. Clear water scour

Sediment movement occurs only on the pillars. There are two kinds:

Local scour did not happen and the process of sediment transport does not occur, when

$$u / u_c < 0.5 \tag{1}$$

Local scour occurs continuously and sediment transport processes do not occur, when

$$0.5 < u / u_c < 1 \tag{2}$$

2.1.2. Live bed scour

Sediment transport occurs continuously, when

$$u / u_c > 1 \tag{3}$$

First motion of sediment occurs when the critical velocity is greater than the average velocity of flow, one of the formulas that is used among many critical velocity [12];

$$u_c = 1.47\sqrt{gD}\left(\frac{h}{D}\right)^{1/6} \tag{4}$$

2.2. The coefficient of superelevation and the slope of the channel

The surface of water flow at the bend line is formulated with the equation of flow motion [2], That is mathematical equations of the surface water in the transverse and extends direction the bend channel by using coordinates cylinder, to reformulate the equations of motion for turbulent flow, the result of a decrease in the formula in the inclination of the surface water in the transverse direction of the bend of the channel Eq. (5) and coefficient superelevation Eq. (6).

$$S_r = C_r \frac{u_m^2}{2gr} \tag{5}$$

The coefficient of superelevation

$$C_s = \frac{H_s}{\frac{u_m^2}{2g}} \frac{r_c}{B} \tag{6}$$

Superelevation coefficient (C_s) is obtained from the model bend of 90° by [2], for equilibrium line bed model, largest value of C_s on the bend of 45° = 4.2 otherwise the smallest value of C_s at the bends of 90° with the value of C_s is 1.7 and for the bend of 0° the value of C_s = 1.5, for the trapezoidal channel model shows a value of C_s approximately = 2.2 while the smallest value happened in the bend of 0° and 90° where C_s = 1.0. The other average coefficient of superelevation (C_s) value is for the channel bottom without sediments approximately = 2.0, while for the channel with the moving bottom or with the sediments bottom C_s = 2.2 [1].

2.3. Grouping type of flow

Numbers grouping Froude and Reynolds numbers by [1]. These groupings are based on the Froude number on the force of gravity according to Eq. (7) namely $F_r < 1$ is called subcritical flow, $F_r = 1$ is called the critical flow, $F_r > 1$ is called supercritical flow, and Reynolds number is based on the grouping force viscosity according to Eq. (8) for $R_e \leq 500$ called laminar flow, for $R_e \geq 12{,}500$ called turbulent flow, and to $500 < R_e < 12{,}500$ called transitional flow.

$$F_r = \frac{u}{\sqrt{gR}} \tag{7}$$

$$R_e = \frac{uR}{\nu} \tag{8}$$

3. Materials and Method

This study is a continuation of a previous study, by using pillars thickness of 3 cm and various quantities of the Froude number and subcritical-turbulent flow limit. The pillars are setup movable at interval of 30°, starting from first point (0°) until the end of channel bend (180°). Assumption has been made in that in one channel bend there is a bridge pillar [13]. The present study specifically examines the effect of the thick pillars as the prototype of a bridge pillar built in the middle flow of the river bend which are predicted could be affect the flow and will result in the change of the cross section of flow. This research was carried out under subcritical-turbulent flow and constantly scours occur, but sediment transport processes will not occur as Eq. (2). Some influence due to the pillar placed in the middle of the channel bend among others, changes in the velocity distribution, the flow turbulence will be increased, changing the topography of the channel bottom line throughout the bend. The essence of all treatment in this study led to changes in the inclination of the water surface in the transverse direction along the channel bends.

To measure the effect of the pillar thickness, flow variation was applied for both with pillar and without pillar. Both conditions were tested by applying F_r = 0.22, R_e = 14,999.94 and F_r = 0.35, R_e = 15,978.54. For the flows with pillar there were pillar interval distance variation of 30^o and 60^o.

Open channels created with width of 0.5 meters and height of 0.4 meters. Materials used are fiber glass, this channel model with fixed discharge. This model channel are divided into three sections from upstream to downstream, the first part is the straight line length of 3 meters, the second part is the channel with a bend of 180^o with radius of 0.75 meters, the third part is the straight line length of 2 meters, at the downstream is made water gate that is functioned only to regulate the velocity of the water, therefore the height of the door can be changed according to the needs of research, flume photo or as shown in Figs. 1, 2 and 3. In Fig. 3 it can be seen that the pillar is placed at the intervals of 30^o, and Fig. 4 is prototype of the pillars.

Model Pillar used in this research are made of wood with thickness of 2 cm and 3 cm, width of 10 cm and height of 50 cm, respectively 7 pieces, for the base material is used the uniform natural sand diameter of 2.16 mm sieve and retained 1.18 mm sieve. Height measurements of water and sediment used high point level gauge with accuracy of 0.1 mm, whereas the water used to measure the velocity of current meter tool.

Based on Eq. (4) it is obtained the critical velocity of u_c = 0.34 m/s. The velocity calculation results are put in the Eq. (2) as the feasibility requirement of the study. On condition F_r = 0.22 obtained u/u_c = 0.56 while for F_r = 0.35 obtained u/u_c = 0.74. Therefore this study is eligible. The next step conducted by the coefficient calculation superelevation Eq. (6).

Fig. 1. Flume looked from side.

Fig. 2. Channels with **bend of 180^o radius r_c = 0.75 meters.**

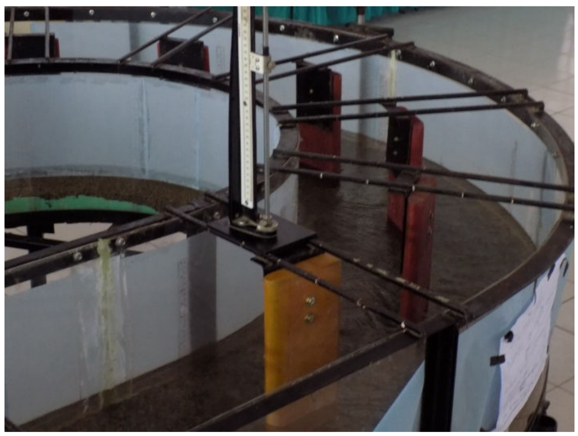

Fig. 3. Pillars and railing point gauge.

Fig. 4. Pillar thickness of 2 cm and 3 cm.

4. Results and Discussion

4.1. Coefficient of superelevation of flow with the F_r = 0.22, R_e = 14,999.94

To find out the coefficient of superelevation on the flow with a pillar thickness of 2 cm and 3 cm, is carry out the velocity and water level measurement in the channel bends done by placing pillars at intervals of 30^o but in the transverse direction of each piece is done by seven points. The first testing flow without pillar, the second with pillar placed in intervals of 60^o, the third are installed of pillars together every interval of 30^o from the beginning of the bend (0^o) and through the end of the bend (180^o). The coefficient superelevation of calculation was done with tabulation of data for water level h = 8.71 cm, u = 0.19 m/s, F_r = 0.22, R_e = 14,999.94 the results can be seen in Table 1 and Fig. 5 with the following description;

- The results of the flow without pillars show that the C_s value is 7.419 at the 90^o bend. This value is greater than the results of all other pillars except the one under 2 cm thickness installed at intervals of 30^o.
- On the pillars of 60^o interval and 3 cm thickness it is obtained that the value of C_s is 7.419 at 30^o bend. This value is greater than the value of 2 cm thickness pillars where the C_s value is 6.930 at 30^o bend on the same test.
- On pillars of 30^o interval and 3 cm thickness it is obtained that C_s value is 7.337 at 30^o bend. This value is smaller than the value of 2 cm thickness pillars where the C_s value is 7.826 at 30^o bend on the same test.
- In general, testing with the pillars the value of C_s the greatest is occurred on bend 30^o. While testing without pillar, the value of C_s happened to bend 90^o.

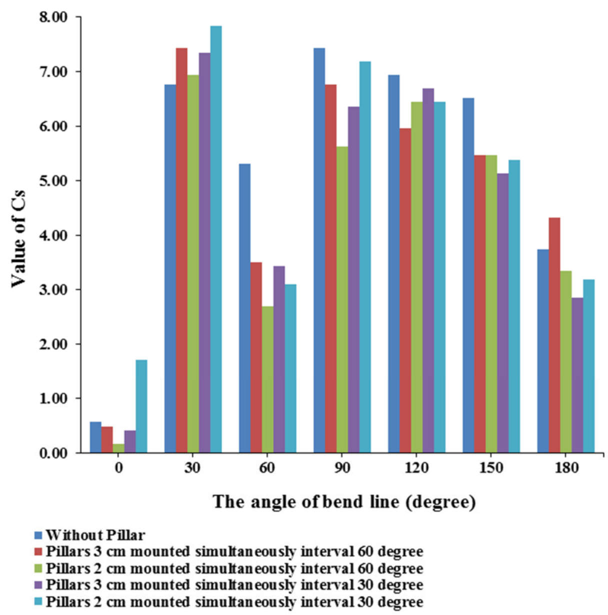

Fig. 5. Value superelevation coefficient (C_s) to flow with F_r = 0.22, R_e = 14,999.94.

Table 1. Values superelevation coefficient (C_s) to flow with F_r = 0.22, R_e = 14,999.94.

Coordinate of measurement	Without Pillar	Pillars interval 60° at 30°, 90°, 150°		Pillars mounted simultaneously interval 30°	
		Thick-ness of 3 cm	Thick-ness of 2 cm	Thick-ness of 3 cm	Thick-ness of 2 cm
C_s 0°	0.571	0.489	0.163	0.408	1.712
C_s 30°	6.766	7.419	6.930	7.337	7.826
C_s 60°	5.299	3.506	2.690	3.424	3.098
C_s 90°	7.419	6.766	5.625	6.359	7.174
C_s 120°	6.930	5.951	6.440	6.685	6.440
C_s 150°	6.522	5.462	5.462	5.136	5.381
C_s 180°	3.750	4.321	3.342	2.853	3.179
C_s Maximum	7.419	7.419	6.930	7.337	7.826

4.2. Coefficient of superelevation flow with F_r = 0.35, R_e = 15,978.54

The same treatment on testing of section 4.1., for high water h = 6.64 cm, u = 0.25 m/s, F_r = 0.35, R_e = 15,978.54, with thickness of pillars 3 cm and 2 cm, corresponding results can be seen in Table 2 and Fig. 6, with the following analysis:

- The results of the flow without pillars show that the C_s value is 6.828 at the 120° bend. This value is greater than the results of all other pillars except the one under 3 cm thickness installed at intervals of 60°.
- On the pillars of 60° interval and 3 cm thickness it is obtained that the value of C_s is 6.875 at 30° bend. This value is greater than the value of 2 cm thickness pillars where the C_s value is 6.169 at 90° bend on the same test.
- On the pillars of 30° interval and 3 cm thickness it is obtained that C_s value is 6.263 at 30° bend. This value is smaller than the value of 2 cm thickness pillars where the C_s value is 6.734 at 30° bend on the same test.
- In general, testing with the pillars of the greatest value C_s occurs on bend 30°. While testing for value of C_s largest without pillar occurred on bend on 120°.

Table 2. Values superelevation coefficient (C_s) to flow with F_r = 0.35, R_e = 15,978.54.

Coordinate of measurement	Without pillar	Pillars interval 60° at 30°, 90°, 150°		Pillars mounted simultaneously interval 30°	
		Thick-ness of 3 cm	Thick-ness of 2 cm	Thick-ness of 3 cm	Thick-ness of 2 cm
C_s 0°	1.318	1.695	1.036	1.130	1.789
C_s 30°	5.980	6.875	5.839	6.263	6.734
C_s 60°	4.191	4.379	4.662	3.579	4.285
C_s 90°	6.686	6.074	6.169	5.651	6.404
C_s 120°	6.828	6.357	5.698	6.169	5.886
C_s 150°	6.498	4.426	4.991	5.227	4.991
C_s 180°	3.908	1.695	3.061	3.720	3.014
C_s Maximum	6.828	6.875	6.169	6.263	6.734

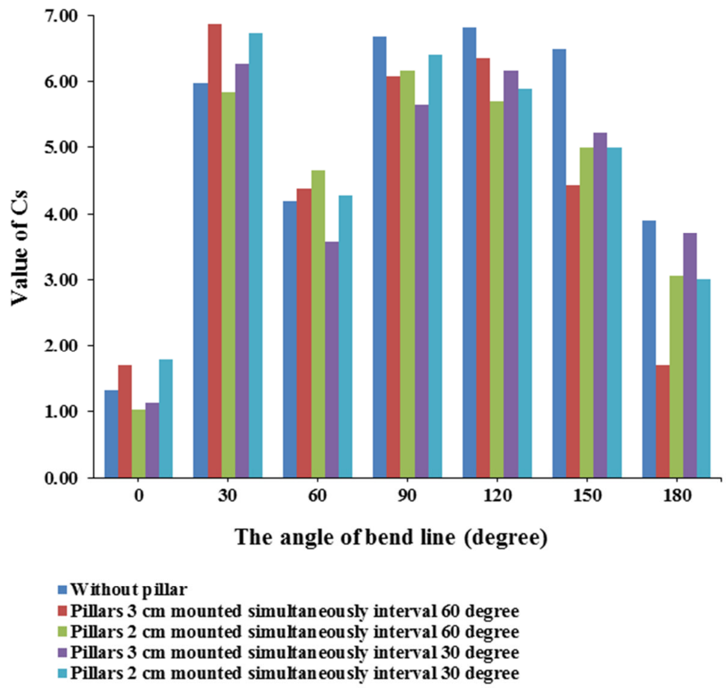

Fig. 6. Values superelevation coefficient (C_s) to flow with F_r = 0.35, R_e = 15,978.54.

5. Conclusions

As explained that this study is to analyze the changes in the coefficient of superelevation by using two kinds of pillar they are the pillar with thickness of 2 cm and 3 cm, first by installing pillars simultaneously at interval of 30^o from the beginning of the bends and at the end the bends, then second at intervals of 60^o, as well as a comparison also measured without pillars, the type used is a subcritical-turbulent flow and satisfy the Eq. (2), the following results;

- On testing pillars at intervals of 60^o for 3 cm thickness pillars obtained C_s value is greater than 2 cm thickness pillars on the same test.
- On testing pillars at intervals of 30^o for 3 cm thickness pillars obtained C_s value is smaller than 2 cm thickness pillars on the same test.
- The highest C_s value occurs on the test using pillars at intervals of 30^o on the 30^o bend.
- In the application, to determine the height of embankment outside of the river bend, the largest value of C_s of 7.826 is used.
- For the next research it is suggested to apply hydraulic conditions for average velocity which is divided by the critical velocity and it must be greater than one. This means that there is gradual movement of sediment. This condition usually occurs in the upstream of a river.

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