Coefficient of Superelevation for the Flow Using Movable Pillar in Channel Bend

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Abstract—To construct a bridge as a crossing building on a very wide river it might not used one span only, therefor, in middle of the river it is needed pillar as support. The existing of the pillars will change velocity distribution, surface water and topography of sediment, especially when the pillar is located on the bend of the river where the very large hydraulic can be hepened. Therefore, this study will be focused on the effect of the coordinate pillar to the superelevation coefficient. The research has done by making a model of channel with and without sediment for the both testing conditions, the pillar was moved by every interval of 30^0 on bends of the channel. Results of the research showed that the greatest value of Cs for the flow without sediment at the position of pillar of 0^0 at the bend of 120^0 is 3.413. On the otherhand, the greatest value of Cs for the flow with sediment was 3.509 wich was given by pillar at position 150^0 at bend of 30^0.

Keyword – Channel Bend, Sediment, Pillar, Superelevation.

I. Introduction

In general, the river can be divided based on its flow at the upstream on the mountains with steep slopes, in general the river is straight whereas in areas with slopes very gently sloping topography near estuary often occurs frequently meanders and also some deltas formed. At the upstream area in general the river is flowing very swift because of its very steep slope, but in downstream area of the river was already entered into lowland with gentle slope, so the water velocity is slow and frequently happened some sediments deposition, which causes the current way of river becomes easy to move and meandering.

To construct a bridge pillar on the bend line of the river required an analysis of the complexity of the flow around the bend line, where the flow lines are not only linear curve, but intertwined spirals which produce some spiral currents and intersect waves. Centrifugal forces that occur in the flow along bend line could affects the rise in water level on the outside and a decrease in the water level on the inside of bend line. Those events are defined as super elevation [5], [8], [10], it is more complicated when on bend line was made pillar in the middle of the river.

Research on the flow have been carried out by researchers both in the closed channel flow (pipe flow) and open channel flow, some relationship researchers who close with this study are Robert Manning (1816-1897) and Osborn Reynolds (1842-1912) with no dimension number well known as Reynolds number, in the case of laminar flow conditions, turbulent, and critical. While other researcher is Froude well known as Froude number.

Grouping flows based on force of viscosity (*viscous forces*) described by Reynolds (Re), $Re = UL/\nu$. Value for an open channel [10]: $Re \leq 500$ is called laminar flow, $Re \geq 12{,}500$ is called turbulent flow, $500 < Re < 12{,}500$ called the transition flow. Grouping flow based on force of gravity described as Froude (Fr) with a dimensionless number $Fr = \bar{u} /(gD)^{0.5}$

In general, the distribution of velocity at a certain depth in the condition of the hydraulic flow regime smooth and rough [4] is; $u = u_*/K \ln (z/z_0)$, with; κ = Von Karman constant = 0.4, u_* = Shear velocity = $\tau_b/\rho = g\bar{u}^2/C^2$, C = Chezy coefficient. Nikuradse, 1933 in [4] to formulate the distribution of base moving velocity (sediment) $u = u_*/K \ln (z/z_0) + B$ with: u = average velocity, u_* = shear velocity, z = high of flow, z_o = thick of viscous flow, z_0 = this value depends on the flow regime where u = 0 at $z = z_0$.

For the velocity measurement in open channel was performed with a *current meter* device, is conducted by dividing the line segment in the transverse direction with $u_{0.8}$ = velocity of 0.8 h, $u_{0.2}$ = velocity of 0.2 h, are recommended [3], [7], [10], while for the shallow water (see terms gauges) measurements performed each segment with a depth of 0.6 h from the base of the channel.

Furthermore, some researchers about bend of the river such as [9], do some research on bend line of 193^0, width of 1.3 m, radius of 1.7 m with dimensions of hydraulic B/h = 10, 10.8, 13, Fr = 0.5 and 0.56, Re = 43,000, 58,000, and 73,000, the results indicated that changes in topography for the discharge of 63 litre/sec with maximum scour on the outside of channel's bend line. While on the inside of the bend channel usually occur the process to become shallow, also demonstrated the presence of scour at 6 point, which is the deepest on the outside of the bend at 70^0. The slope of the line started on angle of 31^0, and scour began to decline after the bend angle of 90^0.

Research carried out [1], especially on local scour caused by the presence of barriers pillars. Study on the depth of scour around bridge pillars in the river bend, by creating a flume model in the laboratory with channel bends of 180^0, rc/B = 4.7 (rc = radius of the bend, B = width of the flume), diameter pillar of 6 cm, shift the pillar from position 0^0, 30^0, 60^0, 90^0, 120^0, 150^0, and 180^0, the depth constant water of 12 cm, sand uniform nature D_{50} = 2 mm with a uniformity factor of 1.7 is used as the base line, flow rates of 18.20 l/sec. The results of this research indicated that the natural flow in the river, especially in the bend line where there are pillars of the bridge greatly affect to the depth of the scouring where the greater turbulence and centrifugal force due to the bend too influential. The results indicated that the deepest scouring was occur at position pillars of 60^0, the second deepest in the position pillars of 90^0, and the shallowest scouring was occur at the position pillar of 30^0.

Researchers of bend of the river with obstacles [2], with flow classification based on flow occurred in rivers, among others; General scour is a natural process that occurs in the river. Scour due to constriction in the groove of the river (*construction scour*). Local scour generally due to the presence of water buildings, for example the pillars of the bridge, there are two kinds of scours namely: *Clear water scour* sediment movement occurs only in the pillars. There are two kinds of Sediment movements: - For u/uc≤0.5, scours not occur and sediment transport processes do not occur. For 0.5≤u/uc≤ 1, local scours constantly occurs and sediment transport processes do not occur. *Live bed scour,* for $u/u_c \geq 1$, occurs due to the displacement of sediment with: u = the average flow velocity (m/s), u_c = critical flow velocity (m/s). Initial sediment motion occurs when the critical velocity is greater than the average flow velocity, some researchers have formulated about the critical velocity [11], by researchers: Shamov (1952), Levy (1956), Goncharov (1962).

Research conducted by Ahmed Shukry, 1950 [10] shows the value of Cs = 2 for the flow without sediment, while the flow with sediment shows the value of Cs = 2.2. Beside that the calculations of research [5] done by creating a physical bend model of 90^0 and the mathematical model in three-dimensional. And calculation of Superelevation coefficient (Cs) the value of Cs = ± 4.2 by equilibrium bed models for bend of 45^0, while the average value of Cs = ± 2.2 by trapezoidal model.

II. RESEARCH METHOD

This research was done in the Hydraulics Laboratory of the Faculty of Engineering, University of Tadulako with the same equipment in [6] well with the size of the channel bends Fig. 1,2 and 3, cross-section, and radius, as well as the size of the sediment, including how to set up the door downstream are all the same. This research is to use pillar moved every interval of 30^0, ranging from the placement of the pillars in the coordinate of 0^0, then moved to 30^0, 60^0, 90^0,120^0,150^0, and the last in coordinate of 180^0, the first of two conditions is done that flow without sediment and the second flow with sediment. Measurement of high level of water, especially the measurement of sediment height used the measuring tool of *point gauge* with accuracy levels of 0.1 mm, while for measuring the velocity was used *current meter tool*, while the research steps as follows;

Fig. 1. Photograph of artificial channel (flume) seen from right side

Fig. 2. Photo of flume taken from inside direction of the bend

a. Research for flow without pillars and sediments
   - Major equipments preparation; Artificial channel (*flume*) including its apparatus, and other support equipment such as *current meters, point gauge, water pump, pillars,* pipe circulation.
   - The study begins by flowing water without pillars and sediment, then measuring discharge by using Thomson triangle door. To adjust the discharge as research needed, can be used stop valve.
   - Once the magnitude of debits in accordance with the needs of the research, the triangle door of Thomson can be replaced with a regular door (rectangle) in order to obtain the high level water and average velocity according to the plan research.
   - Measurement of water surface elevation, sediment and velocity done ranging from 0.6 m before the bend line, and at the area of bend line, measurements were performed on each interval 30^0, and at the last measurement done 0.6 m after the bend line. For each cross-sectional observation divided by 7 points.

b. Research of flow with pillar moved each interval 30^0 without sediment. Research done by installing pillars ranging from 0^0, then the next process is carried out as same as in a point number a, after that the pillar was moved to the bend line 30^0 and so on until the end of the bend line

c. Research with sediment without pillars. The study began with the leveling sediments according to plan height. Then the research process performed as same as in the point number a. After that it water flow should be closed to measure the height of the sediment surface.

d. Research with sediment and pillar moved every interval of 30^0, the research done by installing pillars ranging from 0^0, then later process could be done as same as the point number a, after the pillar was moved to bend line of 30^0 and so on until the end of the bend line, and then for each removal of pillar should be done after measurement of water velocity and water surface elevation then the flow are closed to measure the height of the sediment surface.

e. Measurement results of high level water Fig. 3 sediment and velocity at each cross section then tabulated to calculate the coefficient of super elevation by using formula $Cs = (Hs \times r_c / B)/(u_m^2/2g)$ with Cs = coefficient of super elevation, Hs = difference in water level every segment, r_c = radius of bends, B = width of channel u_m = average velocity of each segment, and g = the force of gravity.

Fig. 3. Mounting pillars on curves 60^0 and water level measurements

III. Experimental Results

A. *Coefficient Superelevation Without Sediment for Pillar Moved Every Interval of 30^0*

Measurements to obtain the value of Cs on the flow without sediment but with the pillar moved each interval of 30^0 performed on range about average height of 6.29 cm, average velocity of 0.15 m/sec, Froude number of 0.19, and Reynolds number of 11,423. The recapitulation of the calculation result as seen in Table I. The calculation results of super elevation coefficient indicated that the first maximum sequence value for pillar at 150^0 Cs = 3.413 at the bend line of 120^0, the second pillar in 90^0 Cs = 3.400 at the bend line of 150^0, the third pillar in the 0^0 Cs = 3.160 at the bend line of 120^0, the fourth pillar in the 30^0 Cs = 3.079 in the bend line of 120^0, the fifth pillar in the bend line of 60^0 Cs = 3.026 at the bend line of 120^0, the sixth pillar in 180^0 the maximum Cs = 2,792 at the bend line of 120^0, the seventh pillar in 120^0 the smallest maximum value of Cs = 2.442 at the bend line of 120^0, showed a tendency to occur at the maximum flow without sediment value of Cs bend line of 120^0.

TABLE I
Superelevation Coefficient at the Bend Line of The Channel Without Sediment and Pillar Moved Every Interval of 30^0 Fr =0.19 Re =11,423

Coordinat	**Without Pillars**	**Placement on coordinates pillar**						
		Pillar 0^0	**Pillar 30^0**	**Pillar 60^0**	**Pillar 90^0**	**Pillar 120^0**	**Pillar 150^0**	**Pillar 180^0**
Cs 0^0	0.239	0.457	0.239	0.405	0.427	0.118	0.098	0.139
Cs 30^0	1.973	2.570	2.071	2.185	3.027	2.106	2.172	2.116
Cs 60^0	1.095	1.114	2.142	1.702	0.177	1.160	1.415	1.563
Cs 90^0	2.081	2.871	2.884	2.374	2.937	2.303	2.764	2.239
Cs 120^0	**3.134**	**3.160**	**3.079**	**3.026**	2.923	**2.442**	**3.413**	**2.792**
Cs 150^0	1.849	2.201	1.792	1.963	**3.400**	2.217	2.465	2.385
Cs 180^0	1.337	0.953	1.976	1.268	1.788	1.155	1.245	0.560

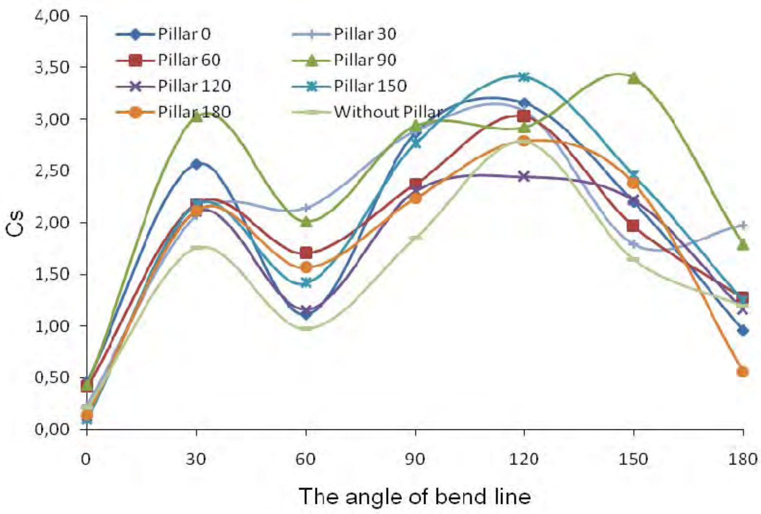

Fig. 4. Curve of relationship between Cs with the angle of the bend for the flow on channel channel without sediment pillar moved every interval of 30^0 Fr = 0.19 Re = 11,423

Taking into account the results of the test without sediment and both without and with movable pillars at intervals of 30^0, as seen in Fig. 4 indicates that there are trends of similarity values of Cs in a row from a large to a small value of Cs, as follows; The large in bend of 120^0, then successively in bend of 90^0, 150^0, 30^0, 60^0, 180^0, and the smallest value of Cs at 0^0. Comparing flow without pillar and with pillar moved every interval of 30^0 to the flow without sediment indicated that the maximum value of Cs for flow with the pillar at 0^0 amounted to 3.160, the pillar at 90^0 amounted to 3.400, and at pillar in bend line of 150^0 Cs = 3.413 is greater than the flow without pillar, and the test other C_S value was smaller.

B. Superelevation Coefficient With Sediment And Pillar Moved Every Intervals of 30^0

The calculation of the value of Cs for flow with sediment and pillar moved each interval of 30^0, as the recapitulation results of calculation of the value of Cs in Table II. Super elevation coefficient calculation results indicated that the largest maximum value of Cs at the first pillar at150^0 Cs = 3.509 at the bend line of 30^0, the second pillar in 30^0 Cs maximum = 3.378 in the bend of 90^0, the third pillar in 90^0 the maximum Cs = 3.352 at the bend line of 30^0, the fourth pillars in the 180^0 Cs maximum = 3.312 at the bend line of 30^0, the fifth pillar in a maximum in 0^0 Cs maximum = 3.259 in the bend line of 120^0, the sixth pillar at 60^0 Cs = 3.242 in the bend line of 30^0, the seventh pillar in 120^0 with the value of smallest maximum Cs = 3.184 in the bend line of 30^0. Showed a tendency to occur at the maximum flow with sediment value of Cs bend line of 30^0.

TABLE II
Super Elevation Coefficient at Channel Bends With Sediment With Pillar Moved Every Interval of 30^0 Fr = 0.19 Re = 11,423

Coordin at	**Withou t Pillars**	**Placement on coordinates pillar**						
		Pillar 0^0	**Pillar 30^0**	**Pillar 60^0**	**Pillar 90^0**	**Pillar 120^0**	**Pillar 150^0**	**Pillar 180^0**
Cs 0^0	0.199	0.563	0.405	0.759	0.364	0.346	0.364	0.724
Cs 30^0	2.679	2.757	2.128	**3.242**	**3.352**	**3.184**	**3.509**	**3.312**
Cs 60^0	1.665	1.799	1.870	1.705	1.920	2.542	1.919	2.123
Cs 90^0	**3.511**	2.383	**3.378**	3.142	2.137	2.732	2.697	2.821
Cs 120^0	2.539	**3.259**	2.671	2.448	2.438	2.597	2.861	2.584
Cs 150^0	1.849	2.181	2.064	2.508	2.463	2.296	2.155	2.848
Cs 180^0	1.344	1.556	1.472	1.495	1.143	1.381	1.323	0.621

Testing of flow with sediment both without and with movable pillars at intervals of 30^0, as shown in Fig. 5 indicates that there are trends of similarity values of Cs in a row from a large to a small value of Cs, as follows; The large in bend of 30^0, then successively in bend of 120^0, 90^0, 150^0, 60^0, 180^0, and the smallest value of Cs at 0^0. Comparison of value of Cs maximum for the flow without pillar to the flow with pillar moved every interval of 30^0, indicating that all value of Cs maximum flow with pillar moved every interval of 30^0 is smaller than the maximum value of Cs for flow without pillar.

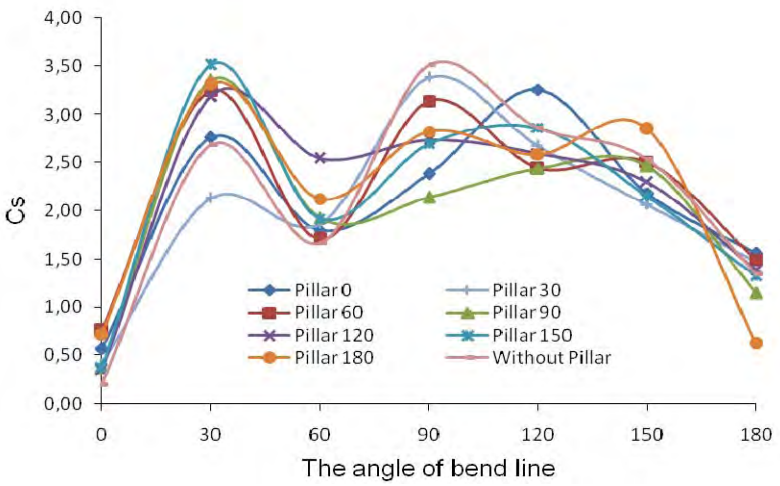

Fig. 5. Curve of relationship between Cs to bend line of the channel with sediment and pillar moved every intervals of 30^0 and without pillar and sediment Fr = 0.19, Re = 11,423

C. Comparison Value of Super Elevation Coefficient for Flow Without and With Sediment

Comparing the results of the flow testing of pillar which is moved every interval 30^0 for two conditions of flow the first flow without sediment and the second flow using sediment, the maximum value of the largest Cs for the flow without sediment on pillars of 150^0 Cs = 3.413 and occurs at the bend of 120^0, while the largest maximum value Cs for flow that using sediment = 3.509 at the bend line of 30^0. Fig. 3 shows the similarity of propensity regular value of Cs on each removal pillar with greatest value of Cs at the pillar placed on 0^0 and the largest value of Cs at the bend of 120^0, while for the flow that using pillars see Fig. 4 the similarity of propensity regular value of Cs on each removal pillar with greatest value of Cs at the pillar placed on 150^0 and the largest value of Cs at the bend of 30^0.

IV. CONCLUSION

The research was conducted without pillar, and with pillars moved every interval of 30^0 in the subcritical turbulent flow and $0.5<u/u_c<1$ for the flow with using sediment and without sediment with the results as follows;

a. The greatest value of Cs for flow without sediment is on the pillar at the bend of 150^0 amounted to 3.413 at bend line of 120^0, while the similarity of propensity maximum value of Cs at the bend line of 120^0, in consecutive at pillar placed in bend line of 150^0, 90^0, 30^0, 60^0, 180^0, and the smallest value of Cs at pillar placed in bend line of 120^0.
b. The maximum value of Cs for flow using sediment, at pillar of 150^0 amounted to 3.509 in bend line of 30^0, and also show the same similarity trend on each coordinate placement of pillars. The similarity of propensity maximum value of Cs at the bend line of 120^0, in consecutive at pillar placed in bend line of 150^0, 30^0, 90^0, 180^0, 0^0, 60^0, and the smallest value of Cs at pillar placed in bend line of 120^0.
c. Comparing flow without pillar and with pillar moved every interval of 30^0 to the flow without sediment indicated that the maximum value of Cs for flow with the pillar at 0^0, 90^0, and at pillar in bend line of 150^0 is greater than the flow without pillar ,and the rest other C_S value was smaller. On the otherhand, flow with sediment indicating that all value of Cs maximum flow with pillar moved every interval of 30^0 is smaller than the maximum value of Cs for flow without pillar.
d. Comparing flow without pillar and with pillar moved every interval of 30^0 to flow with sediment indicates that the maximum value of Cs for flow with pillars is smaller than the maximum value of Cs flow without pillar.

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