NUMERICAL ANALYSIS OF THE BED MORPHOLOGY IN THE REACH BETWEEN CABRUTA AND CAICARA IN ORINOCO RIVER.

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ABSTRACT

The present study aims to evaluate numerically the river bed scouring resulting from sand bars formation and migration, and channel plan forms such as a change of flow width, curved flows, in addition to local scouring due to construction of bridge pier. To achieve the objective of this study, the numerical model International River Interface Cooperative (iRIC) developed by Hiroshi Takebayashi et. al (2009) is employed to simulate and predict the morphological changes in river bed, and empirical formulas are applied to estimate the local scour depth at bridge piers.
(1) The river bed variation is predicted well in terms of numerical model proposed by Takebayashi etal. The bed erosion along the outer bank increases with time in initial stage, and then oscillates temporally. The maximum depth increases with flow discharge.

(2) The local scour depth resulting from construction of bridge pier is estimated in terms of several empirical methods. The results suggest that Andru's method is suitable for study area.

(3) Combining the results of bed deformation and local scour due to bridge piers can be useful for the estimation of the depth of bridge footing.

Keyword: Orinoco River, Bed morphology, Bridge, Local scours, Piers.

1. INTRODUCTION

The National Railway System of Venezuela (NRSV) is a main concern for the nation and is currently under construction. The "Instituto de Ferrocarril del Estado" (IFE) is the authority on all issues and has planned the completion of the NRSV for 20 years. One of the line of the NRSV is Chaguaramas - Cabruta – Caicara with a total length of 201 km that would facilitate communications between the central and southern of Venezuela. The connection between Chaguaramas and Caicara depends on the construction of the third bridge over the Orinoco River.
The global statistics of bridges over waterways show that most bridges fail due to hydraulic reasons such as erosion around piers or abutments. So, it is important to evaluate erosion depth resulting from morphological changes and local scour at bridge piers.
This study aims to evaluate the river bed scouring resulting from sand bars formation and migration, and channel plan forms such as a change of flow width, curved flows, in addition to local scouring due to construction of bridge pier. To achieve the main objective, the numerical model proposed by Hiroshi Takebayashi et. al (2009) is employed to simulate and predict the morphological changes in river bed, and empirical formulas are applied to estimate the local scour depth at bridge piers.

2. REVIEW OF LOCAL SCOUR DUE TO BRIDGE PIERS

The local scour at bridge piers is a subject that has concerned the attention of many researchers for many years. This is due to erosion resulting from the interaction between local flow and sediment transportation. Table 2.1 shows three methodologies which are composed of parameters associated with

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flow discharge, sediment transportation and geometry of the bridge piers to estimate the maximum possible local scour depth at piers.

Table 2.1 Methodologies for estimation maximum possible local scour depth at piers

Researchers	Formulas	
Mazza Alvarez and Echavarria Alfaro	$d_s = 2.4K_sK_\theta b$ Where, d_s is the maximum possible depth scours at piers [m], K_s and K_θ are the shape and alignment factor, respectively, and b is the Piers width [m]	(2.1)
Andru	$\frac{d_s}{y} = 0.80$ Where, d_s is the maximum possible depth scours at piers [m] and y is the water depth [m]	(2.2)
Nakagawa & Suzuki	$\frac{d_s}{b} = 3.4 - 0.9\log_{10}\left(\frac{b}{d_{50}}\right)$ Where, d_s is the maximum possible depth scours at piers [m], b is the pier diameter [m], and d_{50} is the size of the particle sediment.	(2.3)

3. CHARACTERISTIC OF CHANNEL MORPHOLOGY

3.1. Description of the area of study

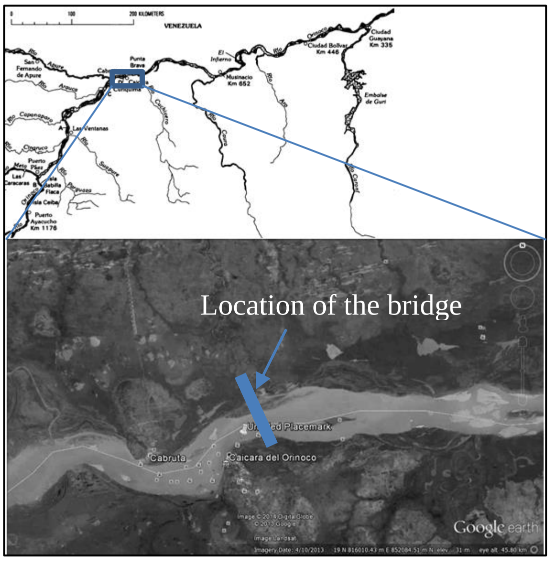

Figure 3.1 Location of the study area. (Source: Google Eath)

Figure 3.1 shows the study area in which the third bridge will be constructed over Orinoco River. The reach between Cabruta and Caircara in Orinoco River are specified as follows: bed elevation ranges between 11.36 m and the 46.26 m; an average discharge is 32,970 m^3/s and velocity is 1.28 m/s; median grain size diameters are 0.26 mm to 0.54 mm; a mean concentration of suspended sediments is 38mg/l. In addition, the ratio of fall velocity of the sediment and the shear stress velocity (w_0/u_*) is 0.61.

For the analysis of the channel morphology of the reach between Cabruta and Caircara del Orinoco in Orinoco River, we need river cross section data, discharge data, water level data, grain size distribution data, channel roughness, etc. For this study, the basic data was obtained from different sources and organization

3.2. Data analysis

Figure 3.2 shows the cross section of interest at which the 3rd bridge will be constructed, and Figure 3.3 shows the monthly flow discharge at Caicara gauge station of Orinoco River, respectively. The width of this section is about 2,600 m and the elevations ranges from 8.70 m to 24.76 m. The maximum discharge is 77,900 m^3/s and the minimum is 2,135 m^3/s in this reach. Usually, the maximum level takes place from around the end of July to the beginning of August.

Figure 3.4 shows the particle size distribution curves in the area of Cabruta. The median diameters for these samples were 0.26 mm at station 3, 0.50 mm at station 5, and 0.54 mm at station 9. The sample at station 3 consisted mostly of fine to medium sand; 100 percent of the material is finer than 1.00 mm and about 3 percent of the material is finer than sand (<0.062 mm).

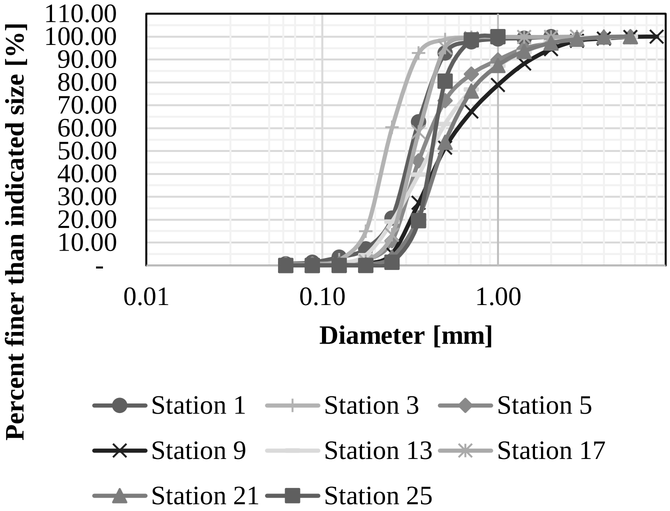

Figure 3.4 Particle size distribution of bed material Orinoco River

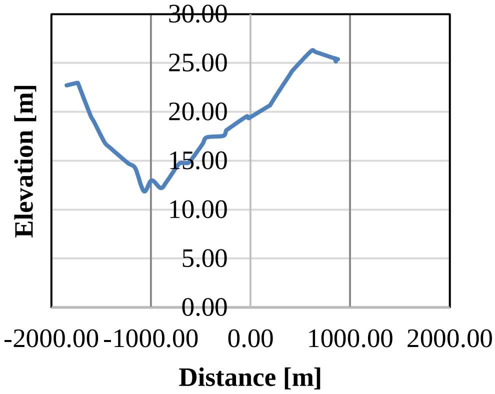

Figure 3.2 cross section of interest at which the 3rd bridge will be constructed

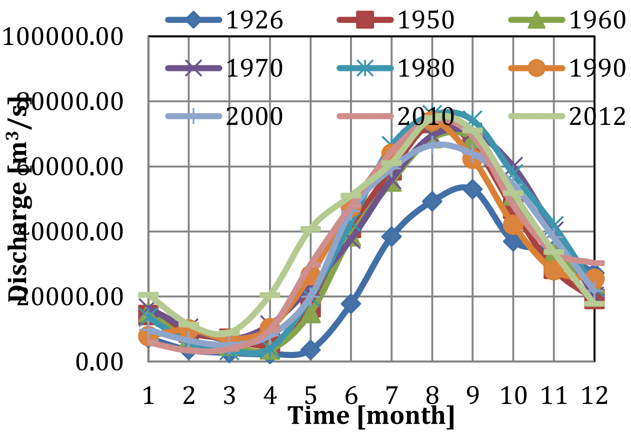

Figure 3.3 Monthly discharge of Orinoco River at Caicara Gauge Station Jan -1926 to Dec -2012

4. NUMERICAL METHOD TO PREDICT MORPHOLOGICAL CHANGES

4.1. Governing equations for the numerical model

The governing equations, which are depth – integrated two dimensional forms are employed in the numerical model. These are composed of mass conservation equation for water flow, suspended sediment of flow body and bed sediment as well as of momentum conservation equation for water flow.

- Mass conservation equation for flow body (Continuity equation)

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = 0 \tag{4.1}$$

- Momentum conservation equation for flow body

$$\frac{\partial uh}{\partial t} + \frac{\partial}{\partial x}(uuh) + \frac{\partial}{\partial y}(uvh) = -gh\frac{\partial}{\partial x}(h + z_b) - \frac{\tau_x}{\rho} + \frac{\partial}{\partial x}(h\sigma_{xx}) + \frac{\partial}{\partial y}(h\tau_{yx}) \tag{4.2}$$

$$\frac{\partial vh}{\partial t} + \frac{\partial}{\partial x}(uvh) + \frac{\partial}{\partial y}(vvh) = -gh\frac{\partial}{\partial x}(h + z_b) - \frac{\tau_y}{\rho} + \frac{\partial}{\partial y}(h\sigma_{yy}) + \frac{\partial}{\partial x}(h\tau_{yx}) \tag{4.3}$$

$$\tau_x = \tau_b \frac{u}{\sqrt{u^2 + v^2}} \tag{4.4}$$

$$\tau_y = \tau_b \frac{v}{\sqrt{u^2+v^2}} \tag{4.5}$$

- Mass conservation equation of suspended sediment.

$$\frac{\partial ch}{\partial t} + \frac{\partial ruch}{\partial x} + \frac{\partial rvch}{\partial y} = \frac{\partial}{\partial x}\left(h\epsilon_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(h\epsilon_y \frac{\partial c}{\partial y}\right) + E - D \tag{4.6}$$

- Mass conservation of bed sediment

$$\frac{\partial z_b}{\partial t} + \frac{1}{1-\lambda}\left(\frac{\partial q_{bx}}{\partial x} + \frac{\partial q_{by}}{\partial y} + E - D\right) = 0 \tag{4.7}$$

Where, h is the flow depth. u, are depth- averaged flow velocity along the longitudinal and transversal direction, respectively, t is the time, g is the acceleration due to gravity, z_b, and ρ are the bed elevation and mass density of water, respectively. σ_{xx}, σ_{yy}, τ_{yx}, and τ_{xy} are the Reynolds stresses, τ_b is bed shear stress, and D are erosion and deposition rate of suspended sediment, respectively. q_b, c, r, and λ are bed load rate, concentration of sediment, factor correction, and porosity of bed sediment, respectively. ϵ_x, and ϵ_y are the x and y components of dispersion coefficient

4.2. Grid generation for numerical computations and boundary conditions.

Figure 4.1 shows the study area in terms of grids generated in general coordinate system. A uniform artificial channel, which is 10 km long and constant bed slope (I= 0.04‰), is attach to both side of the study reach in order to conduct a numerical computation stable. Numerical computations are conducted with the following boundary conditions. At upstream boundary condition is considered a uniform steady flow, the equilibrium sediment transport rate for both bed load Q_b and suspended load Q_s. At downstream of the study area there is no information about water surface elevation. So, for downstream boundary condition is considered the normal depth.

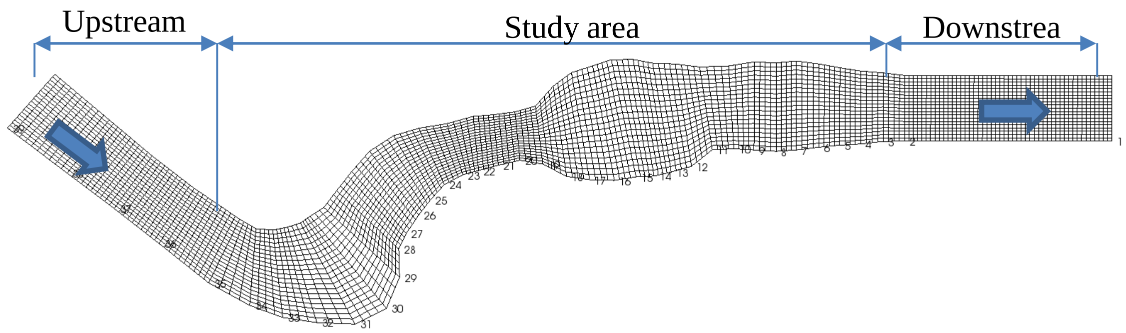

Figure 4.1 Physical plane of study area in terms of the generated grids

5. MORPHOLOGICAL CHANGES IN STUDY REACH

In this chapter shows the results and discussion of the case where is considered a constant discharge of 32,920 m^3/s that is corresponding to the average discharge of all the historical data since 1926. Figure 5.1 and Figure 5.2 shows the bed shear stress distribution and the bed elevation change of the river after 20 days of computation, respectively. In this figures suggest as the bed shear stress increase, the bed erosion happens, on the contrary, when the shear stress decrease the sediment deposition take place. In this channel the maximum bed shear stress occurs: reach between the sections 29 and 26 near to the right bank, expansion (between sections 20 and 18) and contraction in the channel (sections 12 to 10). In those areas also take place the maximum erosion. On the other hand, the maximum deposition take place in areas as: left bank between sections 29 and 26, right bank between sections 25 and 23; also, in this areas occurs the minimum bed shear stress in the channel. Moreover, the value obtained for the cumulative transported suspended sediment is 3.96 x 10^7 ton, value that is bigger than the value obtained in previous study. The reason of this differences are the condition established in the numerical model as: bed material type (uniform) and flow discharge (steady flow).

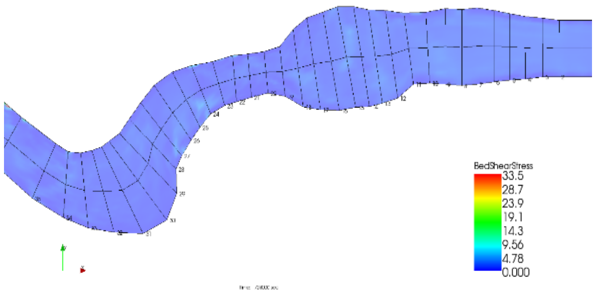

Figure 5.1 Bed shear stress of the Study Area for 20days computation

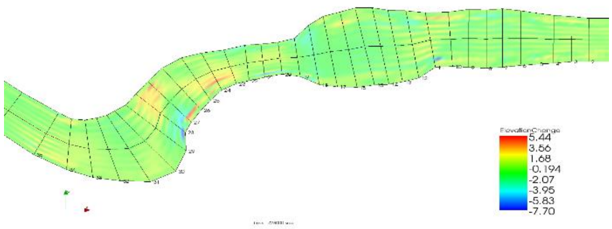

Figure 5.2 Elevation change of the Study Area for 20days computation

Figure 5.3 shows the results of the maximum possible local scour at bridge pier in meters for seven different methodolgies. It can be appreciate that Andru's method provided the maximum scour depth at pier and only depend the water depth. The minimum scour depth is obtained with Yaroslavtziev's method. The values obtained using the methodologies of FHWA and Breuser still are low in one case and in the other only depend of the geometry of the pier. Laursen and Toch, Mazza, and Nakagawa and Susuki present similar values

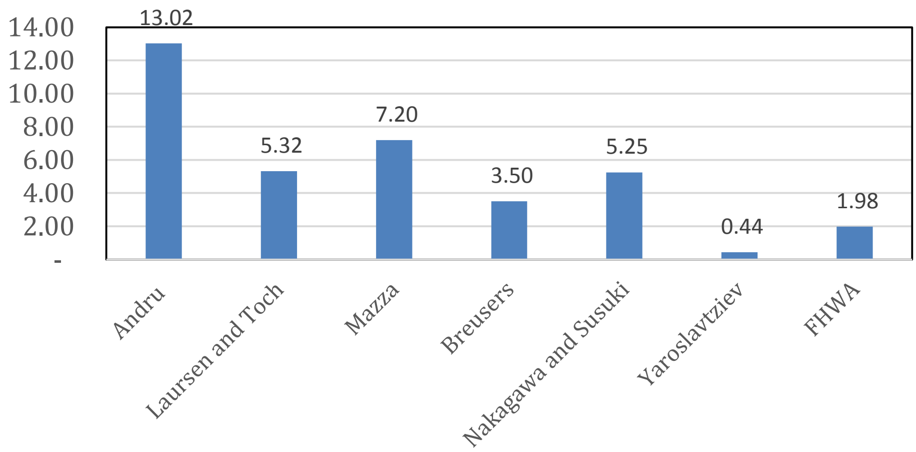

Figure 5.3 Maximum possible local scour depth at piers in meters

For each case that was considered in this research is important to understand the variation in time of the local scour depth at bridge piers. Figure 5.4 shows the variation in time obtained after applied the equation (2.2) corresponding to Andru's method. When is considered the flow discharge of 8,400 m^3/s for 20 days of computation, the maximum local scour (6.89 m) occurs after five days and then start to decrease to a depth of 4.89 m. For a flow discharge of 32,920 m^3/s the local scour is around 13 m and do not present great variation along the time. In the case of 77,909 m^3/s only was obtained computation for 3 days and the behavior is similar as the two other cases.

According to the previous explanation the main reason of the variation of this local scour in each case is due to the change in the bed elevation of the river. In the case with a flow discharge of 8,400 m^3/s is where presented more variation in time.

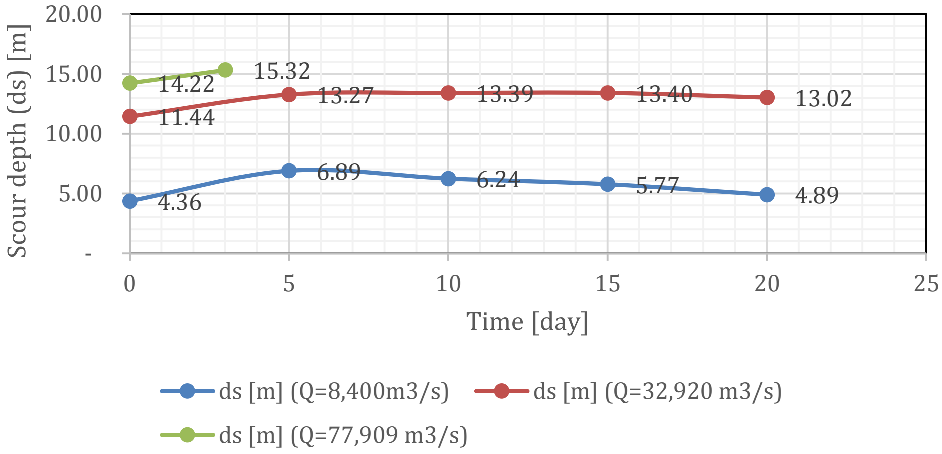

Figure 5.4 Variation in time of the local scour depth at bridge pier

6. CONCLUSIONS

The depth of bridge pier footing should be determined taking the local scouring and river bed evolution into consideration. The results obtained from(present study are summarized as follow:

(1) The river bed variation is predicted well in terms of numerical model proposed by Takebayashi etal. The bed erosion along the outer bank increases with time in initial stage, and then oscillates temporally. The maximum depth increases with flow discharge.

(2) The local scour depth resulting from construction of bridge pier is estimated in terms of several empirical methods. The results suggest that Andru's method is suitable for study area.

(3) Combining the results of bed deformation and local scour due to bridge piers can be useful for the estimation of the depth of bridge footing. .

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