Conference Paper, Published Version

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Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/100089

Vorgeschlagene Zitierweise/Suggested citation:
Yeh, P.-H.; Park, N.; Chang, Kuang-An; Chen, Hamn-Ching; Briaud, Jean-Louis (2006): Maximum Migration Distance of a Meandering Channel. In: Verheij, H.J.; Hoffmans, Gijs J. (Hg.): Proceedings 3rd International Conference on Scour and Erosion (ICSE-3). November 1-3, 2006, Amsterdam, The Netherlands. Gouda (NL): CURNET. S. 727-731.

Maximum Migration Distance of a Meandering Channel

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I. INTRODUCTION

The erosion of streambank is an old yet very complicated problem for geotechnical and hydraulic engineers. Being able to predict the migration distance of a river is crucial because it provides the information for planning, design, and protecting the structures such as bridges, buildings, and bank revetment near a meandering river. Several attempts have been made to estimate the river bankline retreat. Notable are those by Brice [1], Hooke [2], Hickin [3], Hickin and Nanson [4], Keady and Priest [5], Lagasse, Zevenbergen, Spitz, and Thorne [6].

The objectives of this study are to simulate river meandering using large-scale physical models and to develop a simple formula involving the associated physical properties affecting the meander processes to estimate the maximum distance of river meander migration.

II. EXPERIMENT SETUP

The experiments were conducted in a large basin that is 36 m long, 23 m wide, and 1.5 m deep located in the Haynes Coastal Engineering Laboratory at Texas A&M University. The test area is 27m long, 14m wide and 30cm deep in the basin which was filled with sand. An idealized curved channel was dig from the sand bed to investigate the natural river erosion process. A constant head reservoir was connected to the entrance of the channel to provide the desired constant flow rate. A weir at the end of the channel was used to control the water depth in the channel. The experimental setup and test matrix with different geometric and hydraulic parameters is shown in Fig. 1 and Table I, respectively. The channel has an initial trapezoidal cross section with a bottom width of 40 cm, top width of 74.6 cm, bank slope of 30 degree, and depth of 15.6 cm. The channel slope was carefully controlled by adjusting the slope of the sand bed to maintain a constant initial water depth of h = 10 cm along the channel in each test case. Sand with a median particle diameter D_{50} = 0.32mm was used in the tests. Three most important parameters were varied in the tests: The width to radius ratio, R/W, the angle of the channel bend, Φ, and the Froude number, $Fr = U/\sqrt{gh}$ with U being the mean water velocity in the channel. The temporal and spatial variations of water-bank interface, the channel cross-section, and the water elevation were recorded.

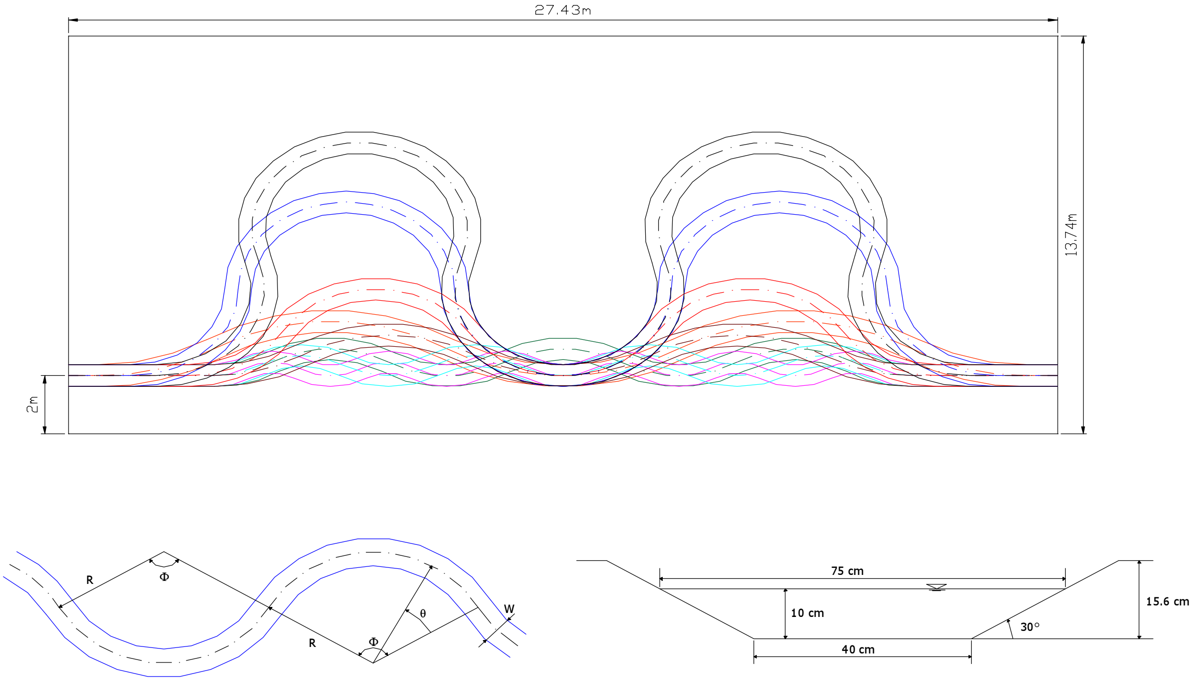

Figure 1. Experimental setup and channel configuration

Table I. Test Conditions

CASE No.	R / W	Φ	Fr No.
01	2	65°	0.29
02	3	65°	0.29
03	4	65°	0.29
04	6	65°	0.29
05	8	65°	0.29
06	4	120°	0.29
07	4	180°	0.29
08	4	220°	0.29
09	4	120°	0.29
10	4	120°	0.29

III. METHODOLOGY AND RESULTS

Figs. 2~4 show the variations of the channel plain form for three representative test cases with a different width to radius ratio, R/W, and bend angle Φ. From these figures, it is observed that the channel migrates in both the lateral and downstream directions; the channel bankline expands laterally and translates to the downstream. The location of maximum erosion distance is behind the channel apex. Figs. 5~6 plot the channel cross sectional profiles at two cross sections within the curved bend in CASE 03. Flow within the curved channel makes deep scour holes along the channel outer bank and sand deposits as the point bar in front of the toe of the inner bank. Due to the sediment supply from upstream and the bank erosion which aggrades the channel bed elevation and the bankfull flow rate running in the experiment, the bankline moves outwards on both sides of the bend with a larger distance at the outer bank. It is clearly seen that if the flow rate were to reduce, the water would flow in the deeper and lower sections of the channel and the water-bank interface would shift to the outer bank.

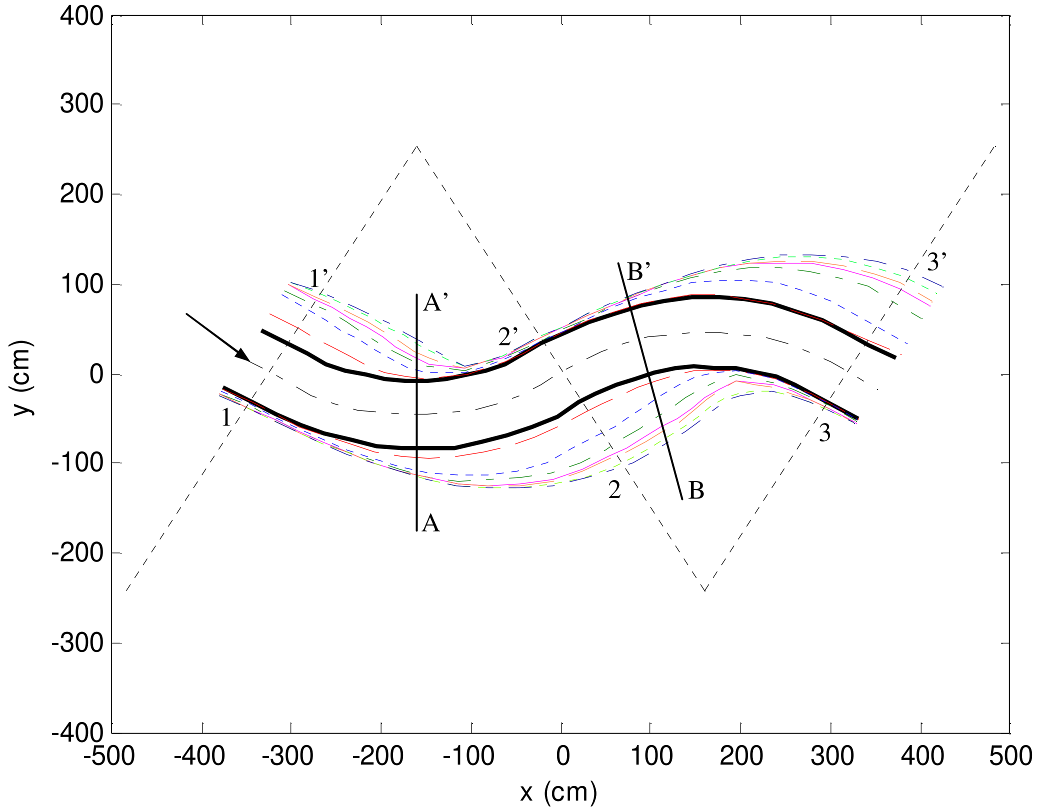

Figure 2. Channel plain form variations of CASE 03

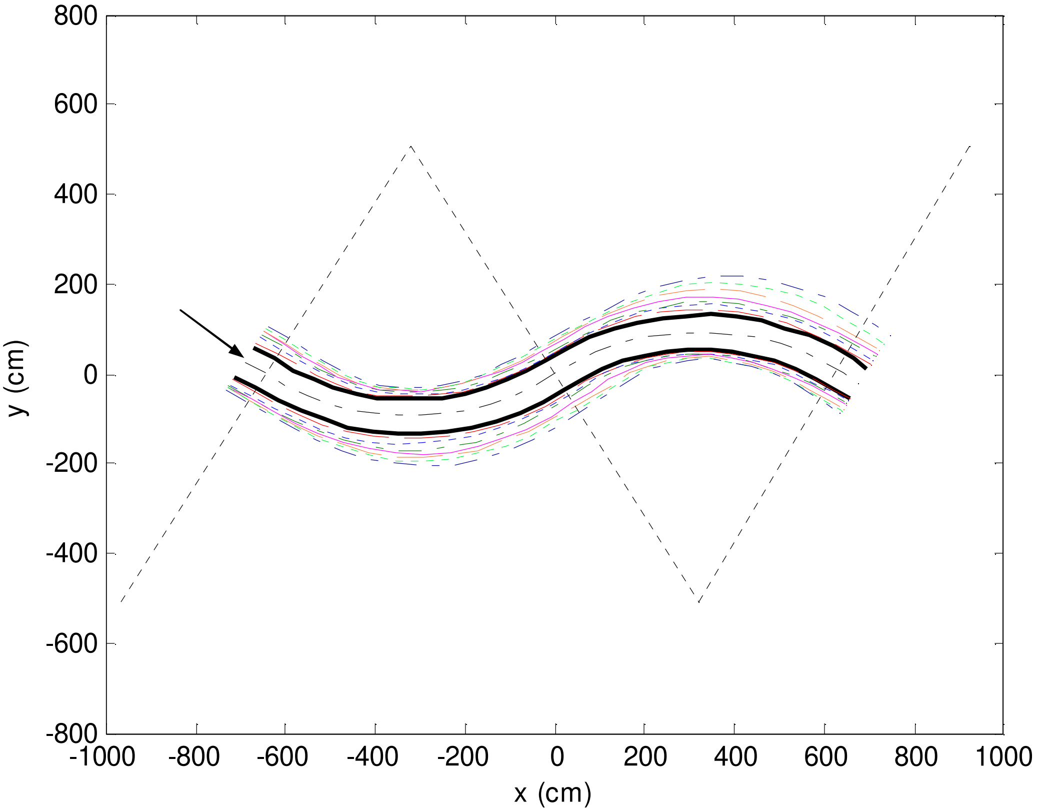

Figure 3. Channel plain form variations of CASE 05

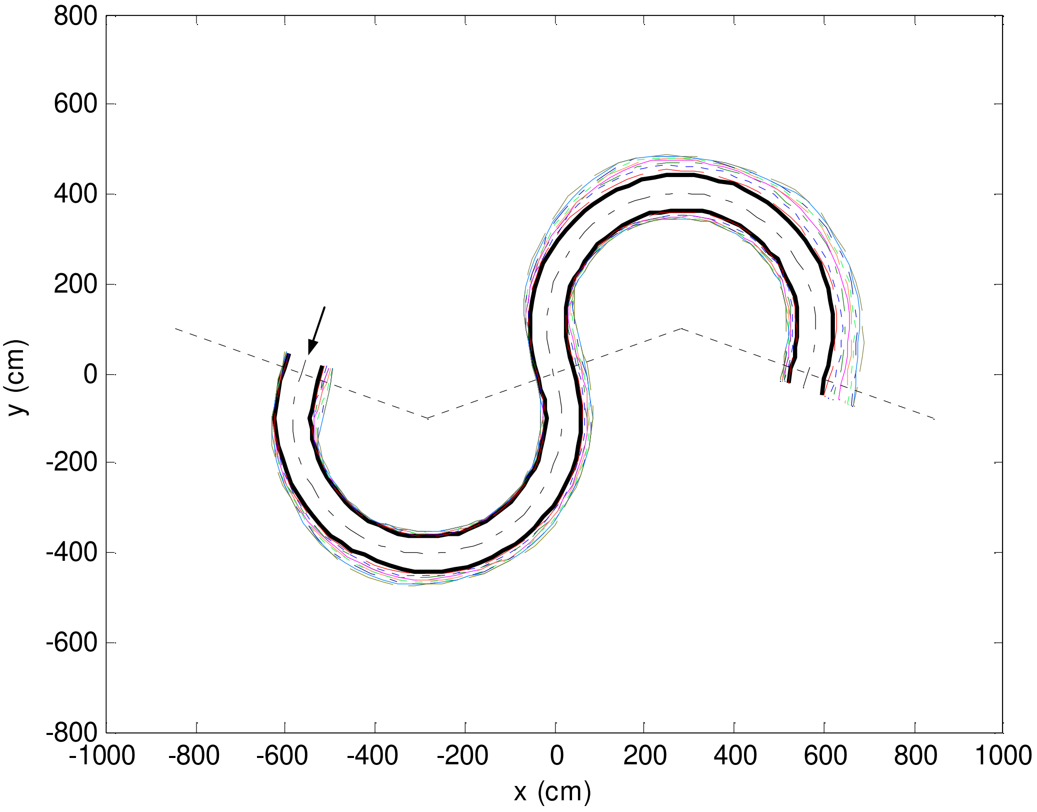

Figure 4. Channel plain form variations of CASE 06

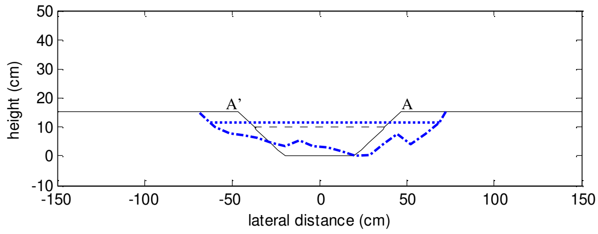

Figure 5. Cross sectional profile of section A-A' in Fig. 2

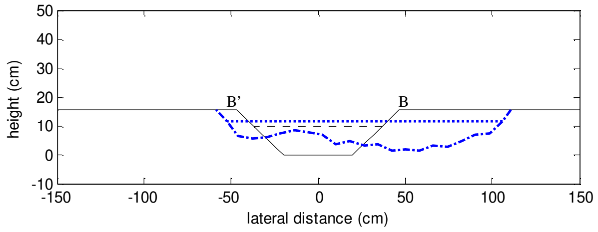

Figure 6. Cross sectional profile of section B-B' in Fig. 2

The erosion of a meander channel cross section underwent a constant flow rate may be expressed by a hyperbolic function. It has a higher initial erosion rate and gradually attains an equilibrium maximum displacement as follow:

$$m = \frac{t}{a + bt} \tag{1}$$

where m is the channel migration distance, t is time, and a and b are constants. The reciprocals of these two constants are indeed the initial migration rate, $\dot{M}_i$, and the maximum migration distance, $M_{\max}$, respectively, i.e., $1/a = \dot{M}_i$ and $1/b = M_{\max}$.

Figs. 7~9 show the bank erosion process in three different cross sections in CASE 03. When the flow starts to erode the bank, the erosion rate (slope) is greater in the earlier stage; the channel migration distance increases abruptly within a short time period. The erosion rate then decreases gradually as the process continues. Finally, the bankline stops moving and the cross sectional erosion reaches an equilibrium state. Figs. 7~9 also show that using the hyperbolic function may be a valid assumption on the description of the meander erosion of soil.

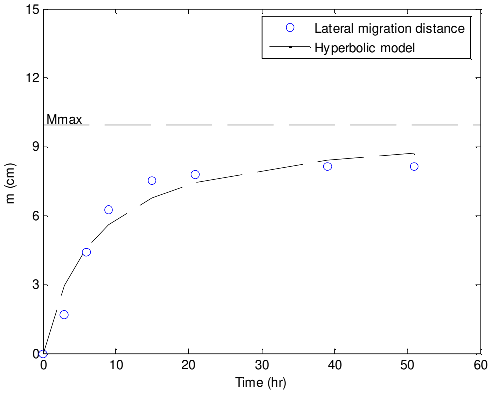

Figure 7. Bank erosion process of section 1-1' in Fig. 2

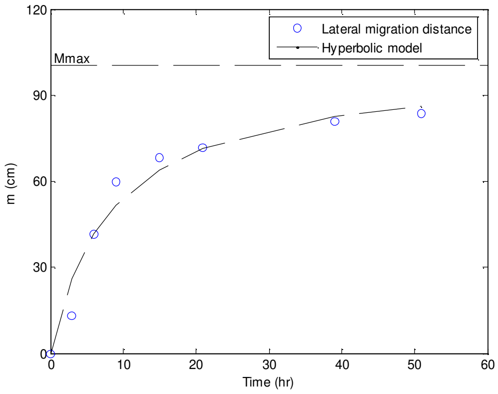

Figure 8. Bank erosion process of section 2-2' in Fig. 2

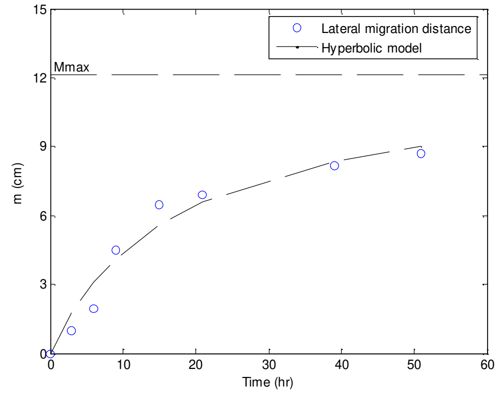

Figure 9. Bank erosion process of section 3-3' in Fig. 2

The maximum migration distance, $M_{\max}$, at each cross section was obtained by curve fitting the measured data points using the hyperbolic model. In the experiment, the data from the second outer bank of the channel and the following third inner bank were used. This is to make sure that the fully-developed secondary current in the channel was accounted for and the back water effect from the channel exit was negligibly small there. The non-dimensional result from one test case is shown in Fig. 10. The result shows $M_{\max}$ along the channel demonstrates a Gaussian distribution function with an obvious phase lag to the channel curvature.

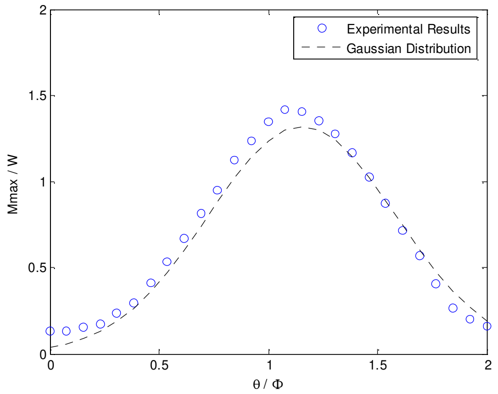

Figure 10. $M_{\max}$ measurement through curve fitting for Case 03

Since the fitted curve in Fig. 10 is close to a Gaussian distribution, the Gaussian distribution function was used to calculate the values of $M_{\max}$ along the channel. The function can be expressed as

$$\frac{M_{\max}}{W} = A\exp\left[-0.5\left(\frac{\theta/\phi - \mu}{\sigma}\right)^2\right] \tag{3}$$

in which A, μ, and σ are three undetermined coefficients and θ/Φ is the normalized angle. Note that $\theta/\Phi > 1$ denotes the following inner bank from the target outer bank. The three parameters in the Gaussian distribution function then were correlated with the width to radius ratio, R/W, the bend angle, Φ, and the Froude number, Fr, using the multi-regression technique. A simple form of the relationship is chosen as:

$$\begin{aligned} A &= k_1(R/W)^{a1}(\phi)^{b1}(Fr)^{c1} \\ \mu &= k_2(R/W)^{a2}(\phi)^{b2}(Fr)^{c2} \\ \sigma &= k_3(R/W)^{a3}(\phi)^{b3}(Fr)^{c3} \end{aligned} \tag{4}$$

where k_i, a_i, b_i, c_i are unknown coefficients. After taking logarithm on both sides of (4), it becomes three linear equations. The coefficients can then be determined using the least-square-error method. After fitting all the 10 cases in the study, the final equations for three parameters in the Gaussian distribution function are expressed as

$$\begin{aligned} A &= 24.2684(R/W)^{0.1457}(\phi)^{-0.5593}(Fr)^{0.7165} \\ \mu &= 32.5558(R/W)^{-0.5981}(\phi)^{-0.5828}(Fr)^{0.1188} \\ \sigma &= 0.3747(R/W)^{0.0888}(\phi)^{-0.0284}(Fr)^{-0.1480} \end{aligned} \tag{5}$$

With the use of Eqs. (3) and (5), $M_{\max}$ can be obtained along the channel. Fig. 11 shows a typical comparison between the prediction equations and the measurement in CASE 02. The result demonstrates that the predicted values of $M_{\max}$ are in good agreement with the measurement.

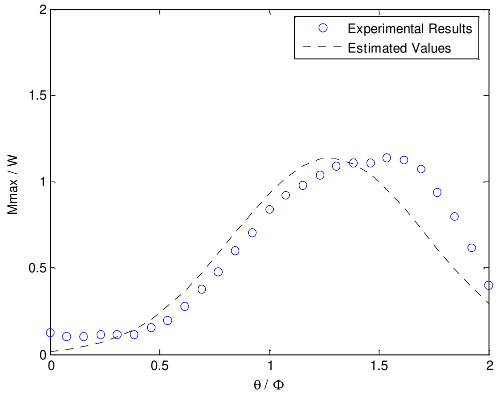

Figure 11. Comparison between prediction and measurement for CASE 02

IV. SUMMARY

Experiments were conducted to investigate the channel meandering migration by varying three important geometric and hydraulic conditions. The results show that the cross sectional erosion process could be modeled by a hyperbolic function. From this hyperbolic model, each cross section would attain an equilibrium state while the total erosion distance from the initial position to this equilibrium state was defined as the maximum migration distance, $M_{\max}$. The magnitude of $M_{\max}$ along the channel bend displays a Gaussian distribution. The peak value of this Gaussian distribution appeared to be behind the apex of the original channel so creating a phase lag. A set of equations were obtained with the three parameters in the Gaussian distribution function determined using the experimental data by varying the initial geometric and hydraulic conditions. The equations were validated by comparing the $M_{\max}$ values with the experimental data.

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