Interaction of Flow and Sediment Discharge To Formation of Point Bars That Lead to Bifurcation – A Review

D.A. Tholibon and J. Ariffin

Abstract - **This paper highlights the progress in theory and experimentation of previous researches on the interaction of flow and sediment discharge to formation of point bars that lead to bifurcation. Numerous studies had made emphasis to the mechanics of point bar development that include chute cutoff and transverse bar conversion. These point bars formation are controlled by the threshold of width to depth ratio of the channel, depending on the shields stress and roughness. The complexity of flow and sediment distribution at bifurcation would depend on many factors namely the nose angle, cross-sectional areas and slopes of the downstream channels. In addition, the stability of the bifurcation depends on the shield stress and incoming flow of the river. In summary, the division of flow and sediment at bifurcation are affected by regional as well as local factors.**

***Index Terms*— bifurcation, braiding, flow and sediment discharge, point bars.**

I. INTRODUCTION

Rivers offer essential habitats and serve as feeding and breeding grounds for a wide range of reverie biodiversity that lives in the river as well as in the river-fringing vegetation. However, the erosion of river bank and the deposition of sediment along the river may cause the river to meander and alter the original form of the river fluvial. The meandering river may generate river bifurcation that may influence the stability of the river system.

As suggested by field observations and flume experiments by [1] the bifurcation is typically the consequence of central bar deposits. According to [2] central bar is deem as the `molecule' of braided rivers. A braided river comprises of a network of interlaced channels which display a significant variation in width, both of the individual channel segments and of the whole channel ensemble. These width variations seem to be associated with bank erosion, bar development and channel curvature.

Study by [3] found out that point bars are the dominant type of bar.

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Bifurcation occurs when a river splits into two branches or a middle bar forms in a channel and commonly occurs in anabranch reach [4].

Local water and sediment transport division need to be understood because it play important role in order to determine the avulsing and river bifurcation and this is emphasized by [5]. A good understanding of sediment distribution process at river bifurcation is crucial for river management [6] as this determines which downstream branch will have the higher discharge. This is important in order to avoid the flooding risk and navigability of both branches as well as the availability of water for vegetation, agricultural and human needs.

[3] concluded that much of the theoretical analysis has been on the formation of bars and development from straight to meandering or transition from meandering to braiding but very little has considered the dynamics and variability of bars within a meandering natural reach. Nevertheless, the flow patterns that cause by point bars and bifurcation need further investigation. This paper is devoted to providing a review on the achievement by previous investigators on the aspect of flow and sediment interaction that lead to formation of midland point bars and bifurcation.

II. Physical And Laboratory Study Of River Bifurcation

Bifurcations have been identified as the primary cause of braiding [7]. Subsequently, laboratory models have for many years been the preferred tool to investigate their dynamics. Explanations of the causes of braiding in alluvial streams fall into two general categories. The first is a functional explanation relating to the occurrence of braiding to a particular combination of environmental factors such as stream discharge, channel or valley gradient, sediment particle size and bank resistance. Secondly through stability analysis of channel, scale bed forms in two phase flow. These two approaches consider the physical sedimentary processes accompanying the onset of braiding that lead to formation of bifurcation.

[8] measured the braiding mechanism using the flume of 10m long and 2m wide with varied combinations of constant discharge and slope but identical bed material particle size distributions. It concluded that braiding in any river depend on local flow and sediment transport conditions at points where braiding occurs and also the sediment mobility conditions in the stream and general flow. It also concluded that the most frequent braiding mechanism is chute cut off and transverse bar conversion.

[9] performed series of experiments on stable bifurcation that form from central point bars deposits. Bifurcation is being unstable if single thread being supplied with unequal

flow and sediment. [9] had also conducted on flume consisting the straight constant width channel followed by linearly diverging reach, ending in a much wider constant width channel. It is observed that large shield values of incoming parameter, the bifurcation was stable and symmetrical. [10] studied the physical model of gravel braided rivers to investigate the adjustment of braiding intensity to step changes in channel forming discharge and the mechanisms by which channel pattern adjustment and maintenance occurs. It showed that local conditions at bifurcations affected by upstream supply of sediment and migration of bars in the upstream channel, making prediction of any bifurcation is difficult. The result showed sediment supply upstream of the bifurcation often affected by an upstream confluence of two or more merging anabranches. [11] investigated the equilibrium configurations of Y-shaped fluvial bifurcation. It concluded that unbalanced equilibrium configurations for high values of the aspect ratio and low values of shield stress. Therefore explained those natural braided rivers concentrate the discharge in a few channels.

III. Field Study On Bifurcation

Field observations highlight various common features displayed by various bifurcations. Analysis of multi decadal timescales for the spatial and temporal variability of channel bars was conducted. The spatial and temporal complexity of bar occurrence demonstrated that more field evidence of the dynamics of bars is needed for river management purpose and for validation of models. Point bars are the dominant type of bar, as expected both in numbers and area. Study by [12] observed that mid channel bars started forming close to riffles, then related to cross sectional over-widening and after some formative events became attached to one of the banks. The changes in sediment supply and in discharge such as from agriculture, dams or mining have been showed to affect the formation and number of bars presents in a reach. The changes in sediment distribution at a river bifurcations often leads to aggradation in one of the downstream that may cause closure to one of the branches [13]

[14] carried out series of field campaign in two streams: the Sunwapta River and Ridanna Creek. It showed that recurring feature of observed bifurcations is a strong asymmetry of their morphological characteristics. It is found out that one of the two distributaries was carrying a far larger discharge. The branch carrying largest discharge is wider and deeper. The formation of an inlet step detected in all monitored bifurcations produce transverse slope that responsible for partitioning of flow and bed load within the downstream distributaries.

[15] described flow field in Jamuna River, Bangladesh. The results showed flow instability can generate a multi thread current and therefore trigger the bifurcation process. [7] reports two series of field observation from two different gravel braided rivers which are characterized by different size and braiding intensity. Bifurcation shows repeated uneven patterns revealed by unbalance water distribution. It is also due to the presence of transverse inlet step that determine the bed topography at bifurcation and lateral shift of main flow towards the external bank where erosion concentrates.

[16] indicated that stability conditions determine by splitting discharge at downstream channel bifurcation. It concluded that for a given shield stress, upstream channel roughness, channel aspect ratio, there is only one asymmetric discharge ratio (Qr) for which the downstream bifurcate channels are stable compare to small perturbations.

[17] provides detailed field analysis study of bifurcation within anabranching cobble gravel rivers. It showed that bifurcation in anabranching rivers are dynamics, complex and both local channel conditions and longevity of fluvial island. The location of bars may affect the bifurcation stability and instability. The stable bifurcation may have lower shield stresses than unstable bifurcation.

IV. Controlling Variables Of Bifurcation

The main controlling parameters are shield stress and aspect ratio of the upstream channel. Larger values of the aspect ratio imply a stronger effect of bed from migration on the system evolution. The bars dynamic will influence the bifurcation amplitude or bar period increased. This is concluded from numerous studies by previous researches.

From a field study conducted by [3], it was suggested that formation of free bars is controlled by threshold of width to depth ratio of channel depending on shield stress and roughness. [11] set the dimensionless parameters characterizing the upstream flow, in determining the equilibrium configuration of the bifurcation. The findings showed that if high value of shield stress and low value of aspect ratio, the discharge distribution is balanced. Higher values of the shields parameters of the incoming flow, the bifurcation kept balanced. Resonant value of aspect ratio, β control the direction towards the morphodynamics influence. It controls the planform shape of the channel. Critical value of aspect ratio sets the occurrence of migrating alternate bars in straight channels.

[18] highlighted the dimensionless parameters that set by water discharge, sediment rate and initial slope that is shield stress, width ratio and sediment size.

$$\upsilon = \frac{\tau_o}{(\rho s - \rho) g D s} \qquad \beta_o = \frac{b_o}{H_o} \qquad ds = \frac{Ds}{H_o}$$

Ds = mean grain diameter; σ = geometric standard deviation of the grain size distribution; υ = shield stress; β = width ratio; the width of the channel at the beginning of each experiment was set lower than βc. Therefore it may create the free alternated bars which imply stable plane bed; ds = relative roughness

The values of shield stress and width ratio at the onset of bifurcation can be related at least for the runs with uniform sediments. The points sits along a critical curve, whereby larger values of the shield stress associated with larger values of width ratio. The diameter of sediment does not affect this relationship. Angle of flow, shields stress and channel width ratio is the main parameters that characterize the flow and channel geometry at the onset of bifurcation.

[19] had observed that both the transverse bed slope and topographic forcing as potential main controls of the partitioning of flow and bedload at bifurcations. According to [9] the diffluences are crucial controls on the downstream partitioning of flow and sediment. It also central to the different modes of channel changes that have identified in braided rivers [20] and control the evolution and sedimentary architecture of deltaic networks.

A field study by [16] stated that flow rate; Q affects network upstream of shorelines. A decrease in Q will cause bifurcation to disappear by sediment filled while an increase in Q by 60% will create a new channel. During the approach to threshold, increase in Q never cause the abandoned of bifurcations whereas increase in shield stress may cause the instability.

[21] categorized the planimetric configurations of braided networks and concluded that braided stream reach a steady state configuration in terms of belt width, number of branches and nodes in a cross section. Two controlling dimensionless parameters namely dimensionless discharge and dimensionless stream power, scaled with grain size and intrinsic length scale with two morphological parameters; width and braiding index were introduced.

V. Numerical And Modeling Study Of River Bifurcation

The river may face varying asymmetrical and unbalances of the system as one of the downstream branch that receive larger discharge is generally deeper and wider. The first effort to reproduce these conditions is within the context of one dimensional (1D) approach by [22].

The 1D model is recommended to predict the long term evolution of channel based on nodal point condition. The 2D effects occur close to bifurcation. The simple channel loop model predicts existence of crucial value of shield parameter. The 1D approach is to investigate the equilibrium pattern and the stability of gravel bed river bifurcation. Although 1D model do not allow the detailed description of flow field and bed topography, it is widely used in river engineering for long term predictions of river morphological development. This model involves the nodal points where appropriate internal conditions must be imposed. This study set the division of sediment discharge within the downstream branches that called nodal point condition as shown in Fig. 1.

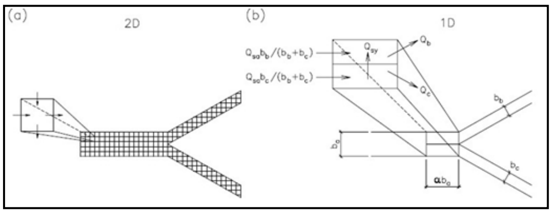

Fig. 1. Scheme of nodal point relationship

As a result, the model offered valuable information on the physical mechanism that rules the development of the bifurcation which sediment transport occurred as bedload. Transverse exchange of sediment encourage by topography effects play significant role to the stability bifurcation and allow equilibrium configuration by different value of flow and sediment discharge into the downstream branches. Performance of bifurcation relate to actual hydraulic conditions and geometry at nodal point. Backwater affects the equilibrium configuration but not stability because the length of upstream channel is sufficient to prevent changes of boundary conditions at the inlet.

The extension of study carried out by [23] looked into the case of channels with erodible banks that the channel which adjusts their width to the real flow environment. The model showed that the removal of fixed bank cause one of the two branches is larger than the other and is fed with greater water and sediment discharges. The model predicts creation of an inlet step that generates a transverse bed slope which crucially affects the partition of sediment discharges into the downstream branches.

The [24] investigated the consequence of migrating alternate bars along the upstream channel corresponding to the transverse division of sediment discharge in the upstream channel vary corresponding with time. The result indicated that effectiveness of alternating bars in governing the bifurcation essentially depends on ratio between time scale of bars migration and the intrinsic time scale of evolution of the bifurcation. If ratio is large, the bar dominates the morphological behavior of the system. The migration may also induce the complete closure of one of the two branches. An extension to the study by [24] was carried out by [21]. They investigated the roles of migrating bars on water and sediment distribution on a lab-scale Y-shape bifurcation with fixed and erodible bed composed of well-sorted sand of which a 1D approach was adopted in their analysis. The results indicate that bifurcation was dominated by bar migration where the main flow frequently switches from one branch to the other until the presence of bar can obviously close one of the two branches. The main controlling parameter is shield stress and aspect ratio of the upstream channel that give the stronger effect of bed form migration on the system evolution.

[13] have demonstrated how a bifurcation evolves using a 1D and 3D models. The 3D model features marked difference in the initial stages due to the formation of local bars and scour at the bifurcation. This is attributed to the spiral occurrence at the local bed and flow interaction from three axes.

VI. Conclusion

Reviews on the previous studies have provided an insight into the mechanics of bar formation that initiates bifurcation. Through this review process, possible controlling parameters of bifurcation are recognized. This should facilitate the forthcoming study on the formation of bars that lead to bifurcation.

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