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Hydrodynamics of braiding river

Abstract

Braided river reaches and alluvial systems are characterized by their multi-threaded planform and agents of sediment transport due to eroding and deposing to form the bars and riffles. In braided river, frequent sediment transport and the quick shifting of the positions about the river channel induce many attentions discussion and relating a complicated consideration of the combinations of disciplines. In this article we introduce its fundamental characteristics and further the complicated mechanism in the literature and methodologies. The braided channel ecology and the management of braided river are mentioned and discussed, especially, the secondary currents, in this paper we explain in detail, the combinations on multiplying of 2-D flow of the velocity fluctuations. The interdisciplinary approach on linking engineers, earth scientists and social scientists concerned with environmental economics, planning, and societal and political strategies in order to fully evaluate the validity and reliability of different selections to various timescales is really sensitive. Furthermore, the requirements of public education on reinforcing about the mechanism of braided river formation will be obviously important and necessary.

Keywords: braided river (channel), secondary current, hydrodynamics, braided index, ecology, management

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Introduction

The plane-view of river channel[1] can be divided into three types: meandering (Figures 1 & 2), braiding (Figures 3 & 4), or relatively straight channels with the varied channel depth due to scouring and deposition of the interaction between water flow depth and velocity on channel deformation forming pools (deep reaches) and riffles (shallow reaches) alternatively. These complex mechanisms from the flow-sediment interaction induce lots of interesting discussion and problems to be solved. Several identified key issues are still remaining, such as: (a) what are the mechanisms on the formation of braided channel? (b) how do the flow and sediment dynamics interact? (c) Why the flow depth influence of the planform development? (d) Do the environment scale factors on both time and space influence the channel hierarchy system? and how? and (e) What is the function of the secondary currents on the morphological development of braided channels?.[2] River braiding (Figure 3 & 4) owns multiple channel ditches on the alluvial islands called braid bars. High sediment loads on coarse grain sizes with the strong flow energy exchange, and in rivers with steeper slopes due to the mainly momentum transfer, rapid and frequent variation on discharge, with weak stream banks and uneasily transported sediment load to deepen the channel depth and widen the channel width to keep the temporarily equilibrium are the characteristics for braided streams and this type channel could be commonly found on gravelly mountain streams, sand bed rivers, on alluvial fans, on river deltas, and across depositional plains.

The braided channel system usually highly moving in horizontal plane-view significantly during flood events. The slope, roughness, and channel depth and width for the corresponding flow patterns, primary velocity profiles, turbulent shear stress and discharge determined by climate including the amount and distribution of precipitation and its intensity resulting runoff amount and the duration alternately influencing the water contain in river bed material, soil, are usually changeable to keep the short-time balance. The continuity equation of one-dimension Q=AV and the relation of resistance of Darcy-Weisbach resistance coefficient, f, which is functions of gravity, wet perimeter, bed slope and flow velocity square are paid much attention and satisfied.[3] They containing six variables are interdependent with different degrees of sensitivity.

Figure 1 Meandering River: Fengping Chi (1). The 9th Bureau, Water Resources Agency, MOEA Taiwan.

Figure 2 Meandering River: Fengping Chi (2). The 9th Bureau, Water Resources Agency, MOEA Taiwan.

Figure 3 Braided River: Xiuguluan River. The 9th Bureau, Water Resources Agency, MOEA Taiwan.

Figure 4 Braided River: Lele Chi. The 9th Bureau, Water Resources Agency, MOEA Taiwan.

Literature review

Going back to the question: "Why is the river channel braded"? "What is the reason of the rivers owing such differing channel patterns"? "Is this channel type flow 1-D, 2-D or 3-D? These questions have made us paying much attention of fluvial geomorphologists and river engineers. Some main independent factors are maintained for determining the river pattern and flow hydraulics, such as: (1) the discharge regime and soil contexture; (2) the slope or gradient both on longitude and lateral directions of the river channels; (3) the erodibility based of the sediment properties.[4] A channel development criterion, the stream power or the unit stream power (the stream power per unit width) is commonly used. The values of this criterion are used to divide the river patterns. In 1957, both Leopold and Wolman, and Lane[5] published results of channel pattern analyses using gradient–discharge charts. They demonstrated that braided rivers plot above meandering ones and that discriminant functions may be determined. Straight channels plotted either on both sides of meandering–braided transition[6] or below meandering channels. Schumm et al.[7] later made the distinction between braided rivers by water stage sediment and the cover situation on floodplain.

Then Rust[8] proposed two parameters: the braiding index, BI[9,10] defined by the number of bars per mean meander wavelength to indicate the intensity of braiding, and sinuosity, SI. The ratio of B/B0, where Bo the braiding parameter11 while braid-channel length B[12] is the another considering parameter on estimating the river patterns. Knighton[13] suggested a classification system for channel pattern that did not include sinuosity as a parameter. Their classification system is based on a continuum concept using three variables: flow strength, bank erodibility and relative sediment supply. Braided reaches are defined as those in which there is a high flow strength, high bank erodibility and medium to high sediment supply. They stated that sinuosity is probably not a sufficiently discriminatory characteristic for classifying any channel pattern. In numerous catchments, human intervention has strongly altered natural river dynamics and the channel morphology should be reexamined including planform configuration, channel width, braiding index, and bed elevation. Improved river management and water resource strategies should take into account of the styles and magnitudes of channel change to avoid or mitigate the adverse aspects of morphological response to future human activities. Specifically, morphological response may affect flood conveyance, channel stability and sediment supply and transport to influence aquatic and riparian ecology. Therefore, some other factors, such as sv= valley slope, Q=discharge (of return period 2 years), D84 =grain size for which 84% of material is finer, depth–width and slope–Froude number, can accurately characterizes the transition. Will be put into analyzing the transition on river patterns.

Methodologies

Alternate bars in rivers and streams are an instability phenomenon related to the characteristic length different scales for the adjustment of flow and form the channel bed irregularities by sediment transport. The vast majority of the experimental supports for the existing theory relies on laboratory experiments assuming a constant discharge. Field studies are rare, which causes the practical applicability of existing theory largely unclear. Crosato[14] derived a predictor for the number of bars per cross-section. Jogendra Nath Sarma[15] presented study, the braiding intensity is estimated by using the braiding index (BI). A key parameter for the development of alternate bars is the width-to-depth ratio of the channel. Is a first-order linear stability analysis of the equations on the mathematics satisfied and with the stability of information on both time and space to provide values of the temporary growth rate? In fact, bar dynamics are under unsteady flow conditions, we just simply the case as the quasi-steady state for the analyses. The reference state is defined by three dimensionless parameters, i.e., the mean width-to- depth ratio β, the mean roughness parameter of d50, and the mean Shields parameter θ, and non-dimension by the h0, the reach-averaged flow depth in the reference state. Of course, higher order linear model could be presented to solve these nonlinear situations problem of braided river flows with certain errors and uncertainties. The analysis of sensitivity and uncertainty test should be in detail progressed on each step. For a river with a width-to-depth ratio β, θ, b and Cf (function of gravity and Chezy C), by a 2D model, and the transportation of sediment separated into bed-load transport and the transport of suspended sediment, by use of the improved knowledge of mechanism on the sediment transport on the concepts of secondary currents. Secondary currents influence and skew the primary velocity profile and the distributions of boundary shear stress to balance the flows and sediments with forming dunes and redistribute the grain based on the gravity action such as the larger particles tending upstream of the dune, thalweg, while the smaller particles being swept to the downstream of dunes. When we analyze the braided flows in the unsteady flow case, the relationship between water depth and discharge, and the one between flow velocity and water depth are loop-rating. Each discharge corresponds two water depth, where one is before peak and the other after peak, meanwhile each water depth also has two flow velocity.

The period of flood coming and the other after peak Figures 5 & 6.[16] At the portion of flood comes, the water depth at the center line position of symmetric cross-section is increasing with the velocity increasing on the opposite direction due to the specific energy conservation. The water depth increases faster than the one near the bank edge at the same water depth due to the friction force supplying from the edges of boundaries. The eddy cycle running from center to the bank edge has the scouring at the river bed and sends the sediment downstream to deposit near the foots of the banks, this function deepen the channel as the narrow-deep form with circulation on the water surface with the maximum velocity beneath the surface and strong momentum exchange with the different energy exchange resulting in a unstable flow situation. After the peak, the opposite operation has been found, the eddy cycle is running from bank to center, the scouring from the bank edge to deposit on the river bed. This function widen the river channel as a wide-shallow form as the natural river with the energy and momentum exchanges in stable condition. These interactions between flows and sediment have to be the most obvious phenomenon and mechanism on the formation of braided, even meandering river, but they are always neglected. There 2D model is needed to explain the situation The discharge and sediment supply played a significant role in the transformation mechanism of channel patterns.[17] In compound channel Figure 7, Luo[18] composited with main channel and floodplains, the momentum and energy exchanges become much more important for the transportation material.

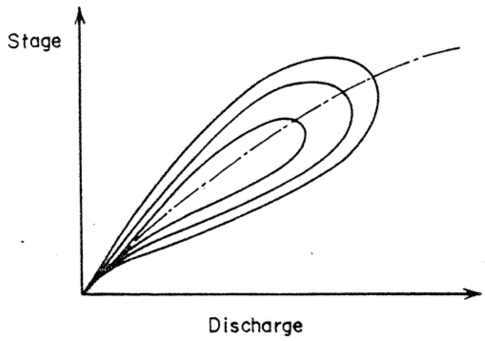

Figure 5 The Loop-Rating Curve, Bird Feather Envelope (Luo, 1988).

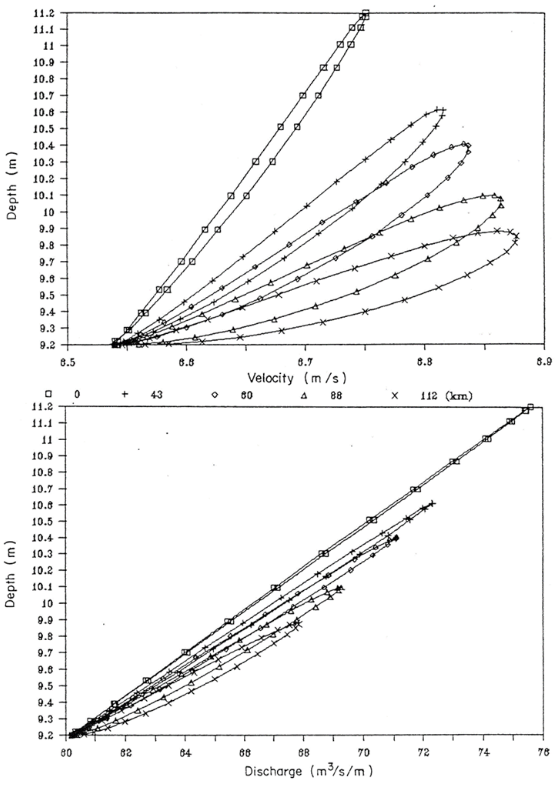

Figure 6 Rating Curves of the Analytical Results between Depth, Velocity and Discharge per Unit width for μ= 10,000 m^2/s Periods 15 days and $S_0=1.55\times10^{-3}$.

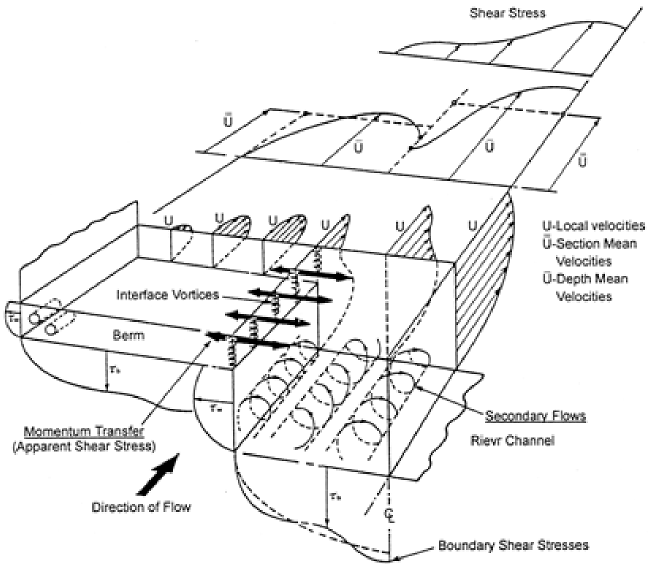

Figure 7 The sketch of the compound channel flows (Luo, 1993).

Because of the different roughness between main-channel and floodplain Figure 8, Luo[18] the shear stress alters the momentum transfer inducing the apparent shear stress at the intersection of main-channel and floodplain with larger influence on energy and momentum exchanges, especially when the water depth just bankful with the small depth ratio Figure 9. Luo[18] and the discharge will be overestimate when you treat the flow situation as a single cross-section. The complicated flow results in a complex phenomenon on material transportation and formation of river patterns.

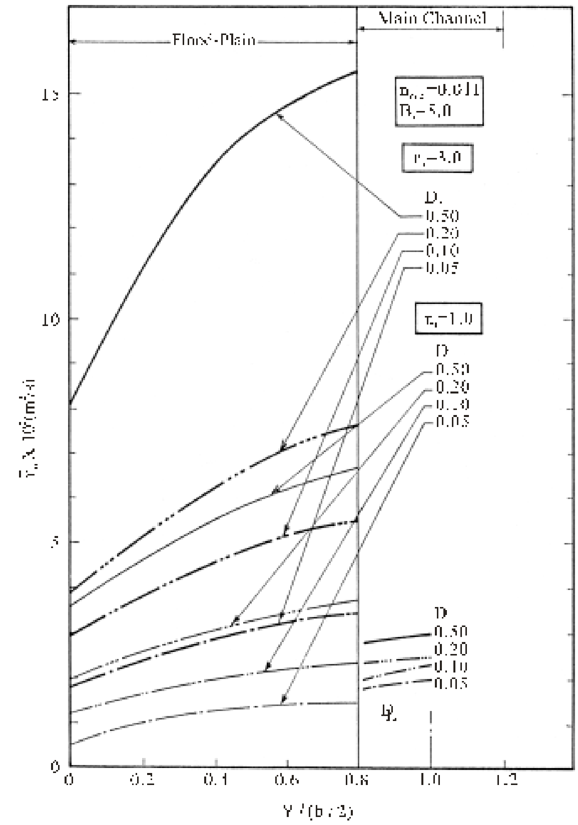

Figure 8 The distribution of depth – averaged turbulent viscosity along the cross – section for different depth – ration and roughness – ratio (Luo, 1993).

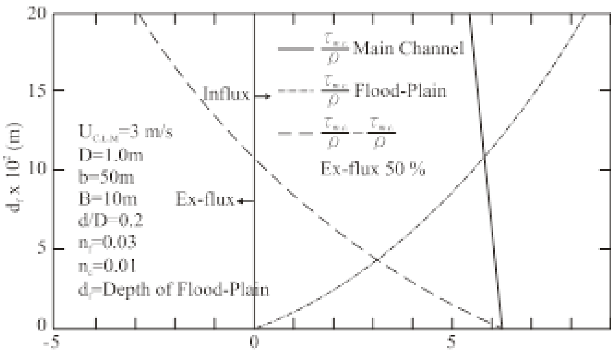

Figure 9 The apparent shear stresses at the edge of intersection above bankful of main – channel, d / D=0.2.

Braided river ecology and managements

Ecology

Parameters i.e. hydrological effects, hydraulics, sediment transport, temperature, and ecosystem, should be included when the ecosystem management considered on braided channel flows. River channel junctions as part of dendritic drainage networks represent longitudinal increases on water and/or sediment runoff to scour or settle on deforming. The artificially channel systems and the man-made river protection constructions also disturb the natural channel flow system such as channel topography on soil material distributions and plane form of rivers by braiding intensity and flow partitioning indices. Flow, with seasonal time-scale, partitioning is crucial for hydrological effects of braided channels on the basis of linear longitudinal gradient and water surface slope, sediment load. Due to these alterations braided rivers are spatially complex, temporally dynamic habitats with the highest biodiversity values along the river continuum especially spatially complex, temporally dynamic systems with high landscape- and reach-scale biodiversity values.

Managements

In consideration of braided river ecology, some parameters,[19] such as hydrological effects, hydraulics, sediment transport, temperature, and ecosystem, should be included. Braided rivers change their geometry so rapidly, the key management questions are difficult to be resolved or even only to reduce the damage from braiding activity because of economic considerations, a desire to reduce hazards, and an absence of ecological constraints. How to maintain the ecological benefits of braided rivers are suddenly become sensitive for scientists and managers to develop strategies to preserve and/or to restore them on engineering or non-engineering methods based on different environmental situations and requirements. These differences show that there is no unique solution on managing braided rivers, but just only case-by-case. For scientists wishing to propose "sustainable" solutions, they must consider the cost-benefit aspects of their options, and the needs and desires of society. This requires an interdisciplinary approach linking earth scientists and social scientists concerned with environmental economics, planning, and societal and political strategies, in order to fully evaluate the economic and social validity of different options for different time-scales. The risk management in terms of property and life associated with protecting the ecology on the ecosystem is the co-repitition question for solving.

Discussion and conclusion

Discussion

Several differences in the underlying assumptions, the theoretical models with the quantitative experiment have been done. The capacity to predict the main bar developments as observed. Bank erodibility can be treated as a major component on braided systems formation on topography and hydrometeorology because of the interaction between water discharge and sediment load on transporting called sedimentology. The identification of a combination of variables that discriminates specific channel patterns has been a significant focus of research in fluvial geomorphology. Very few of these research ideas developed from analysis of large fluvial systems due to many unclear factors, such as the flood scale, the reach scale, the pattern and the magnitude of the upstream sediment supply and the sediment contexture, the channel bank strength, mechanism on the bar and riffle formations, the secondary currents, the influence degree of man-made artificial constructions, and the main-role of the ecosystem. All of them need to be deeply researched.

Conclusion

The initial conditions controlled by the channel slope were favorable for the formation of alternate bars because the slope is very sensitive factor on the sediment transport when we consider the grain rest angle and the 3-D, at least quasi-3D, flow situation. When the disturbance on ground large enough, eventually the sensitive exchange on momentum and energy due to the secondary currents, the natural balance of sediment input and sediment transport were deformed even destroyed. Balancing the sustainable development of such a dynamic braided river valley with compromising natural river ecosystem functions becomes a rather complex task because we need consider the adoption on reducing flood, sediment transport, and bed/ bank erosion measurement at a reach scale on long-term scale, meanwhile, the balancing on human needs in active braided systems for both risk reduction and ecosystem maintenance. The interaction among water, sediment and human should be pay much attention for future research, especially, the real-field observation and theory-methodology development on experiment comparisons. The deep research on the parameter sensitivity analyses and uncertainty test will be powerful tools to understand the clear mechanism for this highly dynamic system on the braided rive formations.[20,21]

Management strategies that have been undertaken government for controlling the braided segments of the river include protecting the developed floodplain by engineered structures and afforesting the catchment. There is no unique solution to managing braided rivers, but that management depends on the stage of geomorphological evolution of the river, ecological dynamics and concerns, and human needs and safety. To propose 'sustainable' solutions, the government authorities must consider an interdisciplinary approach linking engineers, earth scientists and social scientists concerned with environmental economics, planning, and societal and political strategies, in order to fully evaluate the economic and social validity of different options for different timescales and the requirement on public education to help rehabilitate the image and value of braided rivers in the collective mind.

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None.

Conflicts of interest

The author declares there is no conflict of interest.

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