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Rapid channelization and incision into soft bedrock induced by human activity — Implications from the Bachang River in Taiwan

Ming-Wan Huang [a], Jyh-Jong Liao [a,*], Yii-Wen Pan [a], Meng-Hsiung Cheng [a,b]

[a] Department of Civil Engineering, National Chiao Tung University, 1001, University Road, Hsinchu 30010, Taiwan
[b] Water Resources Planning Institute, Water Resources Agency, MOEA, 1340, Jhong-jheng Road, Wu-fong, Taichung 41350, Taiwan

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ABSTRACT

Many Taiwanese river channels have been affected by human activity, such as engineering works and gravel mining. Environmental conditions such as high seasonal precipitation and young sedimentary bedrock exaggerate the narrowing and incising of river channels. The Bachang River is located in southwestern Taiwan, and the 11-km-long channel at its midstream reach has been incised to a maximum depth of approximately 30 m within several decades. Therefore, the morphologic evolution of the Bachang River in southwestern Taiwan provides an illustration of channel changes in response to human activity. The historical data used for this analysis of morphology change include one set of topographic maps and six sets of aerial photographs from the past 100 years. The channel changes are analyzed qualitatively and quantitatively and include the channel planform, longitudinal profiles, channel incision, channel width, and channel cross sections. The results indicate that remarkable channel changes have occurred since the 1980s as a result of human influence. The 11-km-long study reach transformed from an alluvial-type channel to a gorge-type channel within several decades. The maximum accumulated depth of the channel incision is approximately 30 m, with a meter-scale annual average incision rate; the maximum width has been decreased to approximately one-sixth of the original width (448 m). The process of channel evolution is divided into four stages, and we have concluded that the causes of channel change include six factors from two categories: natural factors that include geological conditions, hydrological conditions, and the process of bedrock erosion; and human factors that include gravel mining, lateral structures, and levees. The initiation of channel evolution is triggered by human factors. Finally, we discuss the potential future channel evolution and lessons learned from the case study.

1. Introduction

The morphology of river channels may change in response to human activity and various natural influences. Human intervention may include activities such as dam construction, gravel mining, flow diversion, levee construction, water extraction, and infrastructure construction. The consequences of human impacts include disturbances to stream gradations, which induce an adjustment in the channel geometry and gradient to a new equilibrium. The construction of dams may trap sediment and regulate flow discharge downstream, causing scour below the dam and a reduction in channel capacity (Kondolf, 1997). Gravel mining activity may cause knickpoint migration upstream of the mining pit and induce incisions downstream (Kondolf, 1994). Flow diversion and water extraction decrease the river discharge and may induce channel aggradation. Levee and embankment construction may increase the flow velocity and induce scour around bridge piers at bridge crossings (Gregory, 2006). However, the channel morphology changes with respect to various processes are accumulated spatially and temporally (Reid, 1993). The channel adjustments are not always predictable because of the complex responses from diverse hydraulic and geological conditions.

Without human influence, alluvial streams may change continually between degradation and aggradation in graded conditions (Lane, 1955). Once a river system process is altered by human activity, other processes change in compensation. Numerous examples of river–channel evolution as a result of human influence have been studied worldwide to enhance the understanding of the effects of human impacts on channel adjustments. Channel incision and narrowing are the two main types of channel adjustments in response to human disturbances that are recognized in Italy (Surian and Rinaldi, 2003); deforestation and clearance have caused the sediment supply to increase, which is an early trend (the earliest was in Roman times and major phases occurred in the 18th to 19th centuries) in the Mediterranean region. However, recent trends have demonstrated the adverse effects of damming and river controls on incised channels (Hooke, 2006), and significant channel incision and narrowing has been caused by flood

* Corresponding author. Tel.: +886 3 5712121x54939; fax: +886 3 5724125.
E-mail address: jjliao@mail.nctu.edu.tw (J.-J. Liao).

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embankments and grade control structures in the downstream reaches of the lower Santa Clara River (Downs et al., 2013). In recent decades, extensive channel narrowing in south-eastern France has been demonstrated to be related to human controls (Liebault and Piegay, 2002). Human influence has an overwhelming effect on fluvial geomorphologic changes, and additional research should focus on understanding the future trends of channel evolution for river management.

Bedrock or mixed bedrock-alluvial channels, unlike alluvial channels, retain resistant flow boundaries with a high erosion threshold. Channel incisions in bedrock channels may be hindered (Zawiejska and Wyzga, 2010) because of the slow rate of bedrock erosion (Tinkler and Wohl, 1998; Stock et al., 2005). However, the erosion rate in soft bedrock rivers may be rapid and dominate the evolution of channel morphology (Lai et al., 2011; Huang et al., 2013b; Liao et al., 2013). The characteristics of soft bedrock channels in response to human influences may provide valuable information on the geological factors that affect river behavior.

Taiwan is a spindle-shaped island with a short axis in an east–west direction and maximum length of approximately 140 km (Figure 1A). The Central Mountain Range (highest elevation of approximately 4000 m asl) crosses the island in a north–south direction and is the principal hydrological divide of Taiwan. Topographically, the major streams of Taiwan headwater in the Central Mountain Range flow typically in an east–west direction; therefore, the majority of stream lengths do not exceed 100 km. The annual average precipitation in Taiwan is over 2500 mm, but precipitation levels are concentrated in the wet season from May to October. The stream discharge is highly seasonal and flows rapidly through short and steep channels into the sea. Consequently, many engineering works have been constructed in streams for flood control and water resources. Major flow regulation works, which were primarily constructed from the 1960s to 1970s, have influenced the channel morphodynamics. Bridges and erosion control works are other major causes of channel disturbance. Moreover, instream gravel mining has been considered an economical source of construction material. Human disturbance has significantly modified the nature and rate of river adjustments by altering the spatial and temporal distribution of river forms and processes.

In this paper, the Bachang River in southwestern Taiwan is used to demonstrate the channel morphologic changes that result predominantly from human activity. The human influences are composed sequentially of gravel mining, bridge construction, and weir installation. These interventions on the river bed have triggered a severe bedrock incision of the Bachang River. A series of drop structures have been constructed on the riverbed as countermeasures to protect the bed from channel degradation. However, the exposed soft bedrock is prone to erosion without the armor-layer protection; consequently, the channel morphology has continuously changed toward a gorge-type channel. A comparison of one set of topographic maps and six sets of aerial photographs from the past 100 years has revealed the process of human influence and channel narrowing. The channel change processes are compared temporally and spatially using plane geometries, longitudinal profiles, cross-section geometries, and average channel widths. The possible causes of channel narrowing and deepening are addressed and summarized with respect to natural conditions and anthropogenic influences. Finally, future potential channel evolution and the lessons learned from the case study are discussed.

2. The site location and background

The Bachang River drains approximately 475 km^2 with an elevation ranging from approximately 1940 m in the Fenchihu Mountain to sea level at the estuary in southwestern Taiwan (Figure 1). The total trunk

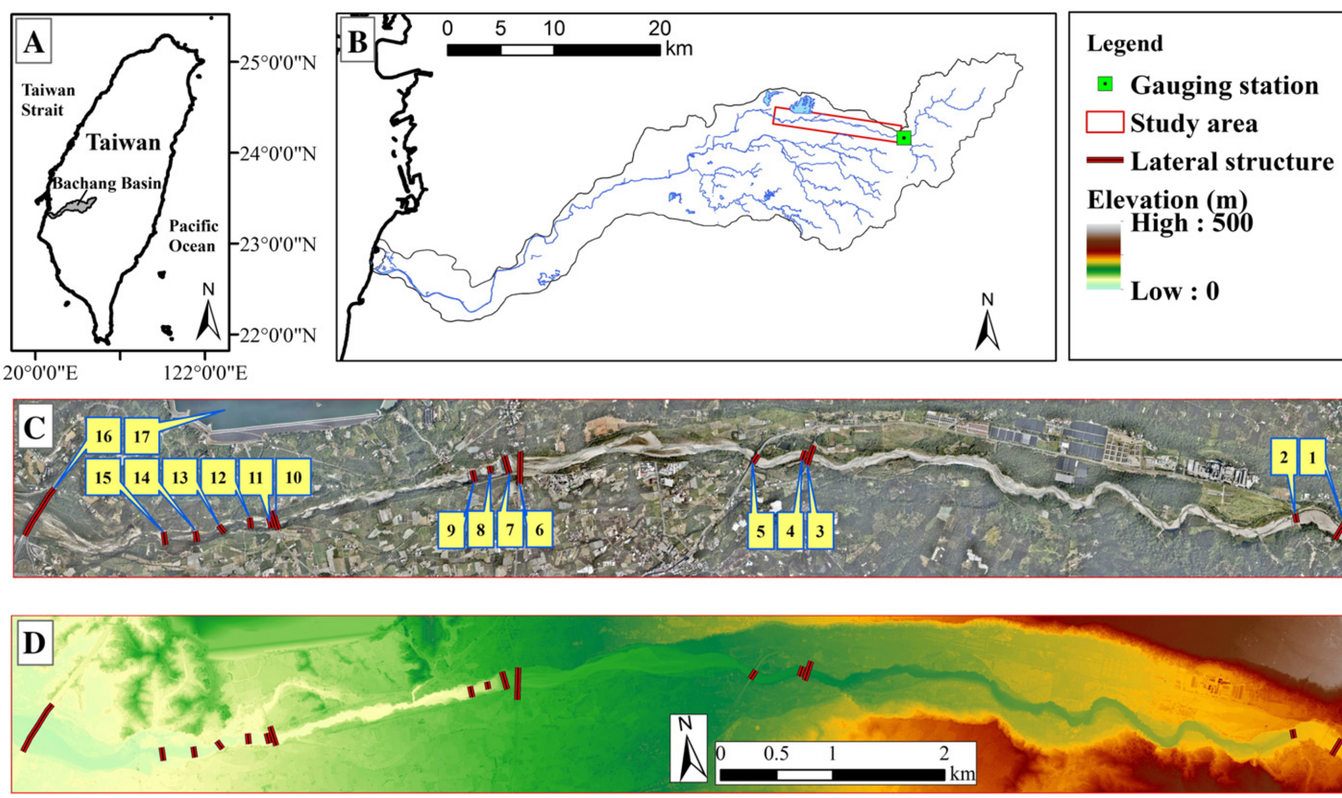

Fig. 1. Location maps of the study reach. (A) The Bachang River location in southwestern Taiwan. (B) The location of the study reach in the Bachang River. (C) The aerial orthophoto of the study reach in 2012. (D) The digital surface model of the study reach in 2012. Flow direction is from right to left. The red thick lines denote the locations of the lateral structures, which include six bridges (Nos. 1, 3, 5, 6, 10, and 16), two weirs (Nos. 2 and 7), and eight drop structures (Nos. 4, 8 and 9, and 11 to 15). The structure names are as follows: 1) Hsingyuan Bridge; 2) Chukou Weir; 3) Wuhuliao Bridge; 4) Drop structure of Wuhuliao Bridge; 5) New Wuhuliao Bridge; 6) Wufeng Bridge; 7) Renyitan Weir; 8) Drop structure No. 18; 9) Drop structure No. 17; 10) Renyitan Bridge; 11) Drop structure No. 7; 12) Drop structure No. 6; 13) Drop structure No. 5; 14) Drop structure No. 4; 15) Drop structure No. 3; 16) Freeway Bridge; and 17) Renyitan Reservoir.