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Fast developed Da-An Gorge: Rapid fluvial incision and knickpoint retreat across a co-seismic popup zone of the 1999 Chi-Chi earthquake, Taiwan

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A 1-km-long segment in the lower Da-An River in fold-thrust belt of western Taiwan was uplifted ∼10 m during the 1999 Mw 7.6 Chi-Chi earthquake, that was subsequently resulting in a 20- to 30-m-deep bedrock gorge within less than 10 years. The amount of coseismic uplift along the channel bed does not fully explain the resulting bedrock channel incision. Using a series of aerial photographs, high-resolution digital elevation models (DEM), and real-time kinematic global positioning system (RTK GPS) surveys, we characterized knickpoint retreat and fluvial incision in the Da-An River gorge. We also analyzed discharge and precipitation data and collected measurements of rock strength and joint plane orientations to better understand the climatic, lithological, and structural influence on the evolution of the actively incising gorge. Two stages of fluvial incision and knickpoint migration are identified in the gorge following the surface uplift during the Chi-Chi earthquake. From 1999 to 2004, 3 to 5 m of alluvium was removed from the channel bed, followed by 3 to 4 m of bedrock channel incision. The knickpoint generated immediately after the earthquake remained where the uplift occurred in 1999. Since 2005, the channel bed has lowered rapidly with local incision rates as high as 15 m/yr. The average upstream knickpoint migration rate over the period 2005 to 2009 was 238 m/yr; total upstream migration from the location of knickpoint formation was about 1190 m. While tectonic uplift formed the knickpoint and set the stage for channel incision, climate played a critical role in accelerating the fluvial response to coseismic displacement. More than 20 m of vertical bedrock channel incision and 1180 m of upstream knickpoint migration occurred primarily during the post-2005 typhoon seasons (May-October). Based on repeat surveys of the Da-An River longitudinal profile and analysis of precipitation and discharge data, we suggest that a discharge threshold of 1200 to 2600 m^3/s is required to initiate incision causing upstream knickpoint migration. However, once the threshold is exceeded, we suspect that bedding dip becomes the primary control on rates and patterns of knickpoint propagation. In a hinge zone of uplift anticline where the bedding dips change from horizontal to upstream-dipping, replacement was observed in the strata dipping upstream. The highest knickpoint migration rates (> 300 m/yr) were recorded in flat-lying, horizontal strata (dip < 10º) where parallel retreat was the dominant process. Overall, the knickpoint propagation followed the process of replacement behavior, in which the height of knickpoint decreases while migrating upstream. Thus, while tectonic processes set the initial conditions for knickpoint propagation in the Da-An River, the response time of the fluvial system to this forcing is strongly dependent on climate and local geology, including lithology and structure.