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Decadal changes in fault-scarp knickpoints by bedrock erosion following 1999 Chi-Chi Earthquake in Taiwan

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Surface ruptures along the Chelungpu thrust fault in west-central Taiwan caused formation of knickpoints (waterfalls) according with bedrock exposure in riverbeds when the 921 Chi-Chi Earthquake occurred on September 21, 1999. Since then the fault-scarp knickpoints have receded upstream at extremely rapid rates, causing bedrock incision for tens to hundreds of meters in length within a decade. The rapid erosion of the knickpoints provides us an opportunity to investigate actual changes of bedrock morphology of the rivers, and here we examine the changes in the knickpoint recession rates during the last decade from 1999 to 2009. Field measurements of the topography revealed that the mean rate of a knickpoint recession in the largest river (Ta-chia) was 3.3 m/y in the earlier 6 years (1999–2005) and 220 m/y in the last 4 years (2005–2009). This acceleration of the recession can be due to the increase in flood frequency and intensity, narrowing of the channel width, and/or anisotropy of rock strength (sandstones and mudstones) along the stream. The other knickpoints showed relatively similar recession rates throughout the decade on the order of 20–60 m/y. These rates are then compared to an empirical model of knickpoint recession, in which relevant physical parameters of erosive force of stream and bedrock resistance are involved as a dimensionless index. The actual recession rates of the knickpoints are considerably higher than those expected by the model, suggesting that abundant sediment particles supplied from upstream catchment enhance the knickpoint erosion. In fact, all the abundant gravels on the riverbed around the knickpoints that are supplied from further upstream areas with different lithology (mostly older sandstones) are quite harder than the bedrock therein. The model analysis for the two time periods for each knickpoint suggests that the changes in their recession rates can be commonly affected by severe flood occurrence in the study area. Also, some of the knickpoints are affected by artificial work of riverbed protection such as check-dam construction and installation of concrete blocks onto riverbed, but the dams or blocks are easily broken and removed after the passing of the receding knickpoints in the bedrock beneath them. Those artificial erosion controls have thus not successfully worked against the extremely rapid erosion of bedrock by the rivers. It should also be noted that the shape of the receding knickpoints is still distinct with a slight decline in their face, and that the gorges downstream of the knickpoints are rapidly widening. Rapid knickpoint recession to form a narrow inner channel is thus a primary response of the rivers to fault-induced base-level change, followed by channel widening downstream of the knickpoint. Further studies such as field monitoring and remote-sensing analysis are then necessary to reveal the spatial extent and time scale of the development of the bedrock river morphology.