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The morphology of beach ridge plains along active margins – a case study from West Aceh, Indonesia

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Beach ridge patterns along active margins can be used to reconstruct abrupt coastal subsidence during large megathrust earthquakes. We use satellite imagery and topographic surveys to measure the build-up of a prominent beach ridge along a 10 km long stretch of the west coast of Aceh, Indonesia, after the complete destruction of the beach during the 2004 Sumatra-Andaman earthquake and ensuing tsunami. We then use the cross-shore morphodynamic model UNIBEST-TC to identify the controlling factors of postseismic coastal development and to determine the preservation potential of seismically modified beach ridges. The western Acehnese coast is characterized by ridge and swale topography reflecting the long-term progradation of the coastline at an average rate of 1.3–1.8 m per year over the last 1000 years. Subsidence of 0.5–1.0 m and tsunami scouring during the 2004 event caused the complete destruction of the most seaward beach ridge and the landward displacement of the coastline by an average of 110 m. However, by 2006 a new 22 m wide ridge had formed. In the following three years the coast prograded by an additional 30 m but has shown shoreline variability of up to 40 m since then. In addition to the spatial data, topographic surveys indicate that the crest of the newly formed beach ridge is 0.8–1.3 m higher than the crests of older beach ridges further inland. The source material for the new ridge is most likely sand transported seaward by the back flow of the 2004 tsunami and stored on the shoreface. In the months and years after the tsunami, this sediment is reworked by regular coastal processes and transported back to shore, leading to the reconstruction of a higher beach ridge in equilibrium with the seismically-induced higher relative sea level. Our modeling results match the field data and show that the recovery of the western Acehnese shoreline after the 2004 tsunami was quick with nearshore sediment transport normalizing to pre-tsunami conditions within two to four years following the event. The stabilization of the shoreline landward of its pre-2004 tsunami position can best be explained by the build-up of a significantly higher beach ridge in response to coseismic subsidence. Observed variability in shoreline position in the order of a few tens of meters since 2009 can be attributed to seasonal wave climate variability related to the monsoon cycle. The effect of postseismic uplift that averages 2.7 cm per year is small and will cause coastal growth in the order of only a few meters over 10 years. This is 3 to 5 times smaller than long-term coastal progradation rates that are driven by abundant sediment supply to the littoral zone. This overall progradational trend will promote preservation of seismically modified beach ridge morphology, which can serve as paleoseismic indicators. In Aceh, another prominent ridge can be found in 640 m distance to the shoreline. It most likely formed in the aftermath of a previous megathrust earthquake and tsunami about 600 years ago matching sediment and coral records for this region.