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Surface deformation associated with the 2013 Mw7.7 Balochistan earthquake: Geologic slip rates may significantly underestimate strain release

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The 24 September 2013 Mw7.7 Balochistan, Pakistan earthquake ruptured a ∼200 km-long stretch of the 60° ± 15° northwest-dipping Hoshab fault in southern Pakistan. The earthquake is notable because it produced the second-largest lateral surface displacement observed for a continental strike-slip earthquake. Surface displacements and geodetic and teleseismic inversions indicate that peak slip occurred within the upper 0-3 km of the crust. To explore along-strike and fault-perpendicular surface deformation patterns, we remotely mapped the surface trace of the rupture and measured its surface deformation using high-resolution (0.5 m) pre- and post-event satellite imagery. Post-event images were collected 7-114 days following the earthquake, so our analysis captures the sum of both the coseismic and post-seismic (e.g., after slip) deformation. We document peak left-lateral offset of ∼15 m using 289 near-field (±10 m from fault) laterally offset piercing points, such as streams, terrace risers, and roads. We characterize off-fault deformation by measuring the medium- (±200 m from fault) and far-field (±10 km from fault) displacement using manual (242 measurements) and automated image cross-correlation methods. Off-fault peak lateral displacement values (medium- and far-field) are ∼16 m and commonly exceed the on-fault displacement magnitudes. Our observations suggest that coseismic surface displacement typically increases with distance away from the surface trace of the fault; however, the majority of surface displacement is within 100 m of the primary fault trace and is most localized on sections of the rupture exhibiting narrow (<5 m) zones of observable surface deformation. Furthermore, the near-field displacement measurements account for, on average, only 73% of the total coseismic displacement field and the pattern is highly heterogeneous. This analysis highlights the importance of identifying paleoseismic field study sites (e.g. trenches) that span fault sections with narrow deformation zones in order to capture the full deformation field. Our results imply that hazard analyses based on geologically-determined fault slip rates (e.g., near-field) should consider the significant and heterogeneous mismatch we document between on- and off-fault coseismic deformation.