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Strike-slip fault in a sandbox: insight of on- and off-fault deformation from analogue modelling

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During large strike-slip earthquakes, the displacement at the ground surface, only partially measured, is often under-estimated in comparison with the amount of slip inferred at depth. The resulting concept of shallow slip deficit is challenged by the precise measurements of surface deformation of on- and off-fault deformation by space imaging techniques, showing that a significant amount of deformation might be accommodated through distributed damage in a zone several hundred meters to kilometers wide around the fault. In this study, analogue modeling is used to quantify the distribution of on/off-fault surface deformation along strike-slip faults over the long term and to understand how it relates to the deep structure of the fault.

To do so, we used a 1.5 m x 1.34 m PVC box, and studied the deformation of a homogeneous sand pack deposited above a straight basal fault, with sand thicknesses varying from 2 to 8 cm. During strike-slip fault experiments, the first structures to appear are the Riedel shears (R-shears) followed by the synthetic shears (S-shears). These structures eventually coalesce to form an anastomosed fault zone, made of a succession of segments separated by geometrical complexities of variable size. Optical imagery is used, at every stage of the strike-slip fault formation, to (1) describe the 3D surface displacement and (2) precisely quantify on/off-fault deformation.

At the initiation of the fault before the formation of the Riedels, a zone of diffuse deformation is highlighted by a positive divergence of the displacement. This diffuse zone is also characterized by a vertical deformation that forms a bulge.

When the displacement Ux parallel to the basal fault has a gradient dUx/dy >= 0.1, we consider that it is "on-fault" deformation, and it is "off-fault, when that gradient is between 0.02 and 0.1.

At the Riedel shear stage, we find 40% of off-fault deformation over a unique Riedel fault and about 60% if deformation is distributed over two Riedels.

Once the strike-slip fault is formed, the ratio drops between 0 to 5 % of off-fault deformation over a fault segment, but the ratio increases to 20% along geometrical complexities.

Moreover, we also show that off-fault deformation around the early Riedel structures partly control the long-lived segmentation and morphology of the strike-slip fault.

Experimental results are then compared to observations and measurements of near-field and far-field deformation obtained along the 2013 Mw 7.7 Balochistan earthquake by Vallage et al. (2015) and Gold et al. (2015). Azimuthal displacements measured in a relay zone (Vallage et al. 2015) are consistent with those observed along our experimental relay zones. Although our experiments were only run with sand, we found a similar distribution of the deformation at the surface. These observations suggest that the distribution of the surface deformation of strike-slip fault earthquakes is inherent to the fault structure, possibly inherited from the Riedel shear stage, and not induced by earthquakes dynamics.