# Hanging wall strain accommodation during thrust reactivation of basement normal faults: comparative analogue modeling of smooth (convex-concave) and flat-ramp (stair-stepping) fault geometries.

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## Previous work

The strain accumulated on a thrust hanging-wall solely as the result of its accommodation to the flat-ramp geometry of a rigid basement footwall, was previously investigated through analogue modeling by several authors (e.g. Mulugeta and Koyi, 1992; Merle and Abidi, 1995; Bonini et al., 2000; Persson and Sokoutis, 2002; Koy and Maillot, 2007). Besides considering fault ramps with different dips, these authors used sand-box experiments to investigated other variables, such as: (1) the effect of variable friction along the fault plane (Merle and Abidi, 1995); (2) the influence of different mechanical behavior of materials (frictional vs. viscous) in the deformable hanging-wall (Bonini et al., 2000); (3) the effect of erosion (Merle and Abidi, 1995; Persson and Sokoutis, 2002), and the recognition of the main different factors controlling hanging-wall thickness (Koy and Maillot, 2007).

## Present work

Given the variability of geometries generally ascribed to thrust-fault ramps, smooth (convex-concave) ones have been recognized as opposite end-members of the flat-ramp (stair-stepping) case (e.g. Cooper and Trayner, 1986). Hence, in the present work, several sand-box analogue modeling experiments were carried out to investigate the influence of a *smooth* fault-ramp – instead of one with a classical *stair-stepping* geometry - in the deformation style of a thrust hanging wall, accommodating strain under otherwise similar conditions to the ones described above. The reverse reactivation of a previously formed 40º dipping normal fault, cutting through a rigid (basement-like) footwall, was specifically assumed in the present case.

Further to the influence of these two end-member ramp geometries (smooth vs. flat-ramp), a preliminary investigation of the behavior of semi-rigid tabular anisotropies, of very high aspect ratio, embedded within the deformable hanging-wall was also carried out through comparing both situations.

## Discussion

The systematic comparison of the results obtained using smooth vs. flat-ramp geometries was carried out both qualitatively (Fig. 1) and quantitatively (Fig. 2 and Fig. 3).

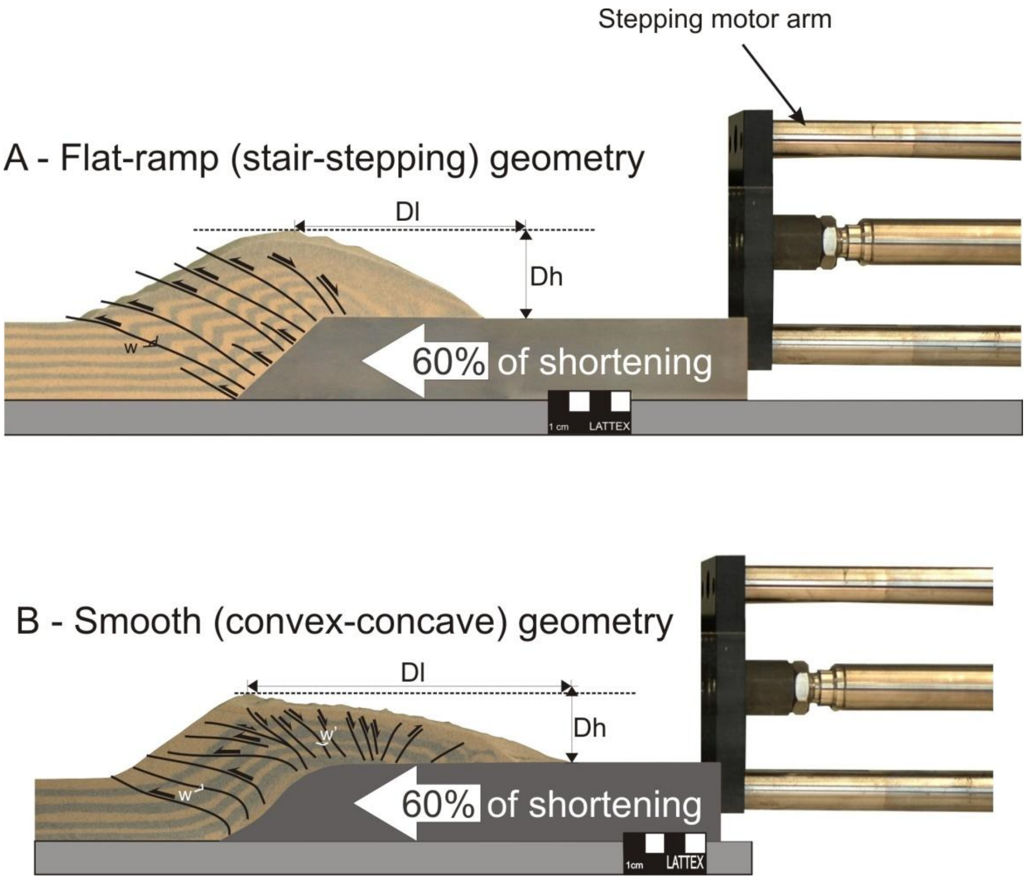


Fig.1 – Experimental results of thrust reactivation of 40º dipping normal faults, for (A) flat-ramp (stair-stepping) geometry and (B) smooth (convex-concave) ramp geometry. Note that the percentage of shortening is 60% in both cases. Dl - frontal wedge length; Dh – frontal wedge height.

This comparison allowed the recognition of several important differences:

1) Thickening above the ramp in the flat-ramp geometry was clearly favored relatively to the smooth geometry case (see Fig. 1);
2) Reflecting what is referred in point 1 above, the frontal wedge height/length ratio (Dh/Dl) was always smaller in the smooth ramp case, for similar incremental values of shortening (see Figs. 1 and 2);
3) In the flat-ramp case deformation in the hanging-wall was accommodated by a relatively lower number of back-thrusts (see Fig.3) at a relatively larger mean distance of each other, exhibiting flatter geometry and more constant dip, resembling an overall more discrete distribution of the deformation above the ramp (see Fig. 1A);
4) In the smooth ramp situation, not only the number of thrusts was relatively higher (Fig. 3), and their mean distance smaller, but their dip clearly varied along the ramp, diminishing in its middle segment (where in some situation was closely horizontal) and increasing again near the top transition to the flat zone (see Fig. 1B);
5) The seemingly more discrete nature of the deformation in the flat-ramp case was also expressed by the overall geometry of folds affecting the hanging-wall, which in this case corresponded to well defined, relatively wide, kink-bands (see Fig. 1A);
6) The geometry of sub-horizontal kink-bands in the hanging-wall of the smooth ramp was less evident, with individual well defined short-limbs of the kink-bands lacking (see Fig. 1B).

Based on these differences, a more gradual (i.e. less discrete) distribution of deformation is seemingly favored by the smooth ramp geometry. In particular, this is reflected in the mechanics involved in the reactivation of the back-thrusts as normal faults, when

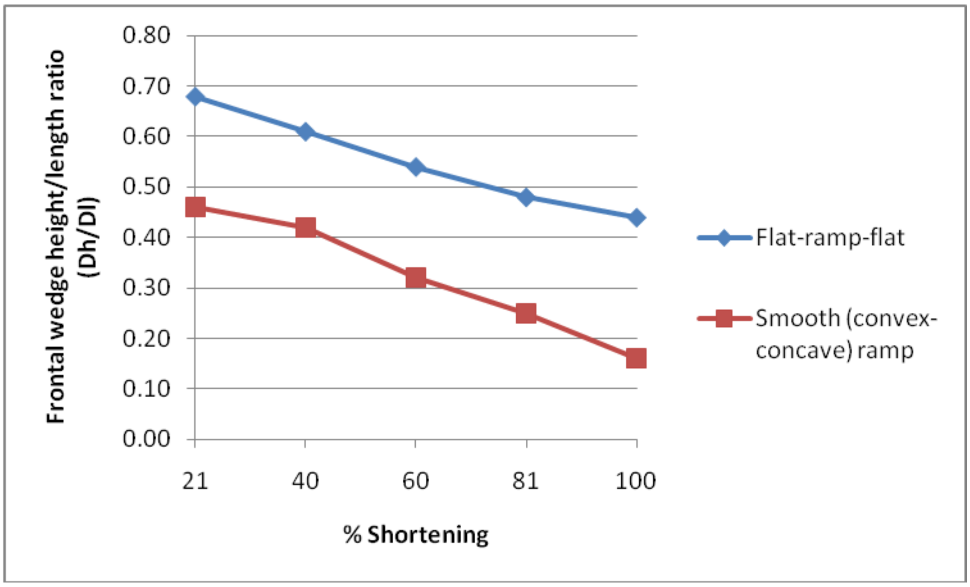


Fig. 2 - Comparison of frontal wedge height/length ratio (Dh/Dl) achieved during thrust reactivation of normal faults, for different percentages of shortening, either in the case of flat-ramp-flat (stair-stepping) geometries, or smooth (convex-concave) ones.

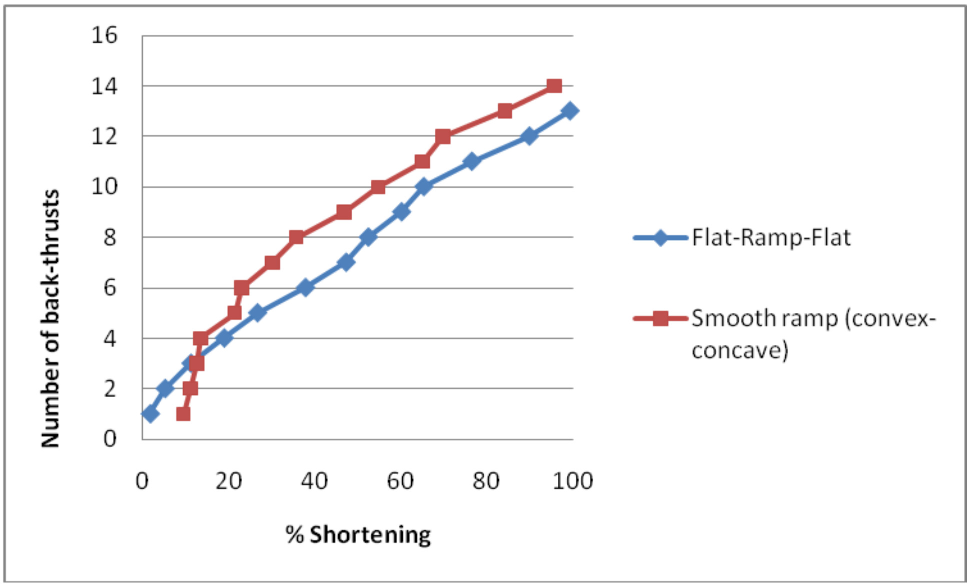


Fig. 3 - Comparison of number of back-thrusts vs. percentage of shortening formed during thrust reactivation of 40º dipping (normal) faults either with flat-ramp (stair stepping) geometries or smooth (convex-concave) ones.

the deforming hanging-wall oversteps the transition between the ramp and the (top) flat (Bonini et al., 2000).

As reported by the quoted authors, in the case of the flat-ramp geometry this reactivation is more abrupt, occurring when the back-thrust passes the sharp singularity corresponding to the transition from the ramp to the (top) flat zone, suddenly rotating, increasing its dip, and entering the compatible normal-fault reactivation field (op. cit.). Accordingly, our flat-ramp experimental results show that all back-thrusts reactivated as normal faults passed beyond the same transition, and are all rooted in the top flat zone (see Fig. 1A).

The newly obtained results concerning the smooth ramp geometry strongly suggest a more gradual and complex transition to the normal-fault reactivation stage, in which individual back-thrusts undergo a greater amount of rotation (from closely horizontal to minimum dips of ~59 º, compatible with normal fault reactivation), exhibiting conflicting kinematics along different segments of their curved surfaces (see Fig. 1B). Accordingly, the transition between back-thrusting and normal faulting domains is not so sharp as in the flat-ramp geometry, with some of the normal fault reactivation occurring before the structures reach the transition from the ramp to the top flat zone.

These assumptions are also seemingly confirmed by the obtained preliminary results concerning the behavior of high aspect ratio tabular anisotropies, implanted within a hanging wall deforming under similar conditions.

## References


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